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The Comparison of The Parallel Scanning And Serial Scanning Scheme of The Optical Mechanical Scanning Infrared Imaging System

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Abstract

The scanning scheme plays an important role for the performance and quality of the optical mechanical infrared imaging system. This paper analyzes and computes the influence of 1/f noise, cold baffle effect, heterogeneity of the multiple units sensor on the system sensitivity of the parallel scanning and serial scanning, makes a qualitative analysis on the effect of the system pass band and sensor's defect on the imaging quality of these two scheme systems, makes brief comparison of these two scheme's corresponding technologies, cost, and production feasibility, etc. From these two scheme's analysis, computation comparison, we can see that the serial scanning scheme is better than the parallel scanning scheme with regard to the system sensitivity, imaging quality and corresponding technologies, cost, production feasibility. So when designing the optical mechanical scanning infrared imaging system, we should give consideration to the scanning scheme as an important factor. As for the product planning, the selection of scanning scheme should be paid more attention to.

Keyword

Infrared imaging, serial scanning, parallel scanning, 1/f noise, cold baffle

The scanning scheme plays an important role for the performance and quality of the optical mechanical infrared imaging system. When we design the infrared imaging system, scanning scheme should be a question which

claims precedence over sensor and optical system. The selection of a suitable scanning scheme will lay a good foundation on the system's performance, quality and other corresponding technologies. When choosing or evaluating an infrared imaging system, the scanning scheme is important for its performance and quality. This paper will synoptically compare the serial scanning scheme and the parallel scanning scheme of optical mechanical scanning infrared imaging system,, with regard to system sensitivity, imaging quality, corresponding technology, cost and production feasibility, etc.

According to the scanning scheme, the optical mechanical infrared imaging system could be divided into serial scanning scheme, parallel scanning scheme and serial parallel combination scanning scheme. If each sensor unit scans a small part of the viewing field respectively (one or two lines), all these small fields that are scanned by each sensor unit are combined together to form the full viewing field, this kind of scanning scheme is called parallel scanning. If each sensor unit scans the full viewing field, the multiple units characteristic is shown by the accumulation processing, this kind of scanning scheme is called serial scanning. The serial and parallel combination scanning is between these two scanning schemes, so it's technical capacities possess those of two schemes. In order to simplify the description and comparison, this paper only compares the serial scanning scheme with the parallel scanning scheme. In fact, there are few absolute serial scanning systems. The serial and parallel combination scanning scheme whose scanning speed is far higher than that of the parallel scanning scheme (more than 10 times) has the characteristic that belongs to the serial scanning scheme, so this scanning is included in the serial scanning scheme. Thus this paper is in fact the comparison of the parallel scanning scheme with the serial and parallel combination scanning scheme that has the serial scanning characteristic.

1. Comparison of system sensitivity between the different schemes

1.1 Some general concepts

The sensitivity of infrared imaging systems is measured by NEFD (noise equivalent flux density) and NETD (noise equivalent temperature difference). These two parameters reflect the capability of the system itself from different aspects, for an identical system, NEFD and NETD are corresponding, in order to simplify, we only use NEFD.

The multiple unit form of NEFD is shown as following:

$$NEFD = \frac{4f}{\pi D^2 K_{(obsc)} \tau_0 K_{(b)} K_{(m)} D^*} \left(\frac{\Omega}{V N_{El} N_{TDI} T_{(h)} K_{(sc)}} \right)^{1/2} \qquad /2$$

where

f ----- focal length of optical system

D ----- optical aperture

$K_{(obsc)}$ ----- optical sheltering coefficient

τ_0 ----- optical transmittance

$K_{(b)}$ ----- energy utilization efficiency of image speckle

$K_{(m)}$ ----- image motion shrinking coefficient

D^* ----- normalized detecting degree

Ω ----- scanning view field

V ----- line array visibility

N_{El} ----- number of parallel scanning sensor unit

N_{TDI} ----- number of serial scanning sensor unit

$T_{(h)}$ ----- scanning period

$K_{(sc)}$ ----- scanning efficiency

$N = N_{El} \cdot N_{TDI}$ $\quad N$ ---- total number of sensor units

paste $\propto \frac{1}{\sqrt{N}}$

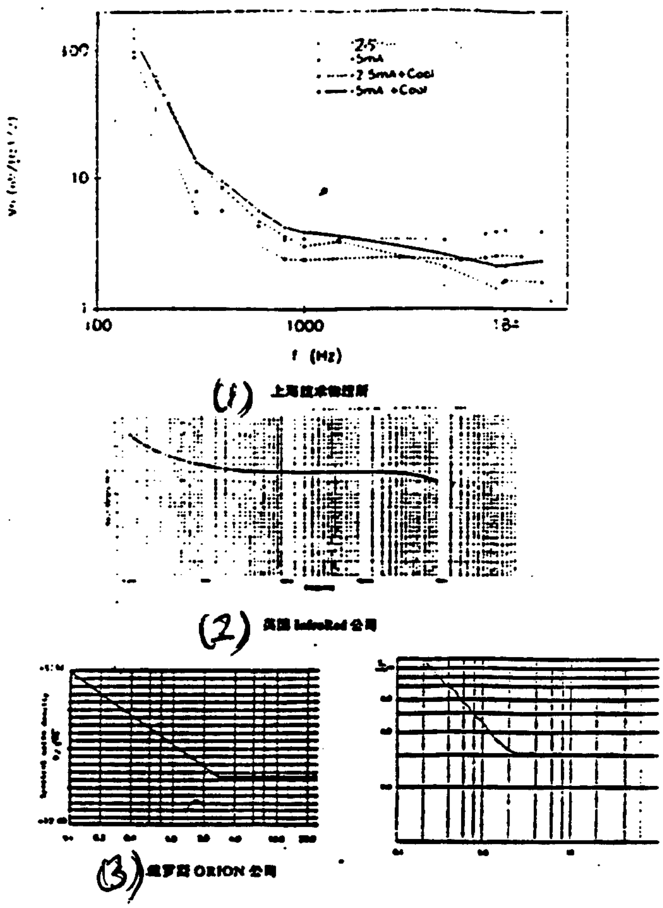
From the equation, we can see that the sensitivity of infrared systems relates to the total sensor unit number, but does not relate to the scanning mode (how the units are arranged). This is only a conclusion in general, in other words, this is the conclusion under the condition that the multiple unit sensor is the ideal sensor. In the practical

situation that the sensor being used is not ideal, that means the sensor has relatively larger 1/f noise, cold baffle effect and severe heterogeneity. Thus the actual D* values that using the same performance sensor but employing different schemes have fairly large difference, this difference causes the difference in system sensitivity. The following will analyze and compute the effect of these kinds of factors.

1.2 The effect of 1/f noise

Currently being used infrared sensors all have 1/f noise, the 1/f noise of some infrared sensors is fairly large, such as the long wave photo conductor mercury cadmium tellurium sensor (PC.MCT), and the photo voltage indium stibite sensor (PV, I_nS_b), both are commonly used models. Taking long wave PC.MCT sensor as example, the sensor's noise power spectrum curves of different manufacturers are shown in figure 1. We can see that most of the 1/f noise knee point frequencies of the sensors that are produced by foreign and domestic manufacturers are in the range 1KHz ~ 2KHz, the knee point frequency of the best product report we can see is 500Hz.

There is a very big difference between the infrared system bandwidth with different scanning scheme, when most of the infrared systems' frame frequencies are 20 ~ 50Hz, the parallel scanning system's bandwidth is several kHz, the serial scanning system's bandwidth is dozens of kHz ~ 1MHz. The relationship between the sensor's noise and the system pass band is shown in figure 2. From the figure we can see that in the parallel scanning system's pass band, the 1/f noise occupied a large portion. This means that the system's average noise spectrum density is larger than the narrow band noise spectrum density on the D* measuring frequency point (usually this frequency is 1KHz, sometimes it is 10Khz or 20KHz). In the serial scanning system, the 1/f noise occupies a small portion, the system's average noise spectrum density hardly changes.

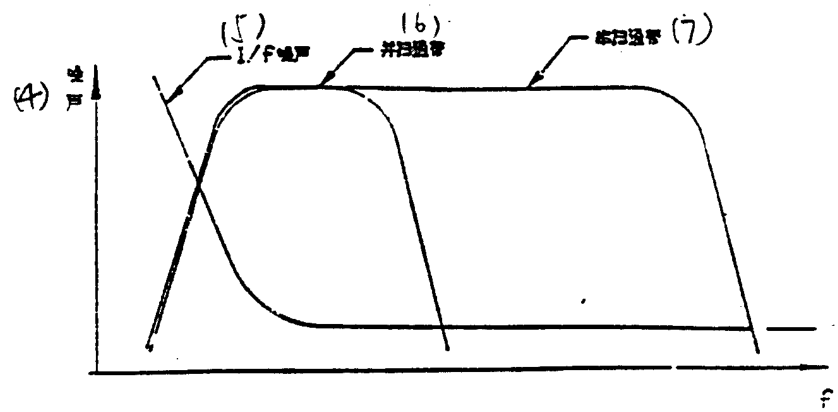


(1) Technical Physics Institute of Shanghai

(2) Infrared British Corporation

(3) ORION Corporation of Russian

Figure 1. The noise spectrum curves of PC.MCT long wave infrared sensors



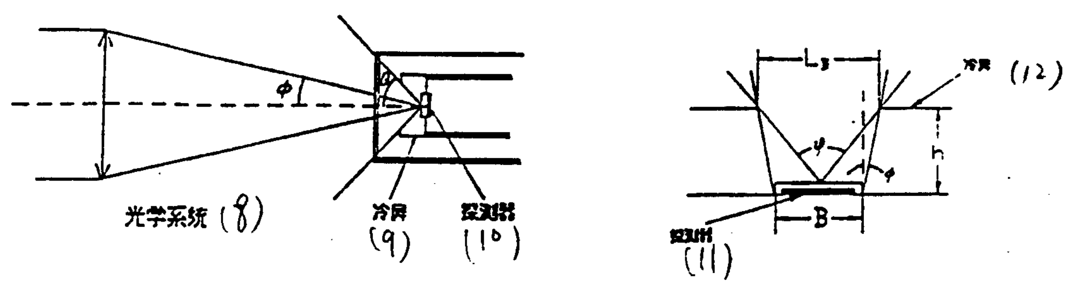
(4) noise

(5) 1/f noise

(6) parallel scanning pass band

(7) serial scanning pass band

Figure 2. The relationship between the sensor's noise spectrum and the infrared system's pass band



(8) optical system

(9) cold baffle

(10) sensor

(11) sensor

(12) cold baffle

Figure 3. The relationship between the cold baffle angle and the optical aperture

$$\because D^* = \frac{R_V}{V_n}\sqrt{A_d \Delta f} = \frac{R_V\sqrt{A_d}}{V_n/\sqrt{\Delta f}}$$

If D^* reflects the actual system's performance, in the equation should be regarded as the sensor's average noise spectrum density in the system's noise pass band.

From the analysis above we can see that, an identical sensor has different #4 values in the systems with different scanning schemes, obviously this value of the serial scanning is bigger than that of the parallel scanning. In reference 2 the author gave the computing method and formula for this effect:

$$D^* = K_{(n)} D^*_{BLIP} \qquad (2)$$

$$K_{(n)} = \left(\frac{\Delta f}{f_n \ln K_f + \Delta f}\right)^{1/2} \qquad (3)$$

$$\Delta f = f_H - f_L \qquad (4)$$

$$K_f = \frac{f_H}{f_L} \qquad 5)$$

where

D^*_{BLIP} - ----- D^* value of background limitation or without 1/f noise

f_n— ----- 1/f noise knee point frequency

f_H— ----- upper limit frequency of the system's pass band

f_L— ----- lower limit frequency of the system's pass band

Using equation (3) we can compute the data in table 1.

Table 1. $K(n) \sim f_n, \Delta f, K_f$ data table

Δf(KHz)	$K_{(n)}$ K_f / f_n (Hz)	30	100	300	1000	3000	10000
5	1500	0.70	0.65	0.61	0.57	0.54	0.52
	1000	0.77	0.72	0.68	0.64	0.62	0.59
	500	0.86	0.83	0.80	0.77	0.75	0.72
50	1500	0.95	0.94	0.92	0.91	0.90	0.89
	1000	0.97	0.96	0.95	0.94	0.93	0.92
	500	0.98	0.98	0.97	0.97	0.96	0.96

From the equations and data we can see that the wider the system's bandwidth #10, the less the 1/f noise's effect. The smaller #11 (that means the higher the lower limit frequency), the less the 1/f noise's effect. But if #12 is small, the system's imaging quality is bad (see details later), so #13 can not be too small. During the selection, computation and practice of parameter #14 in the parallel scanning system which has large 1/f noise proportion, we found that the system's sensitivity is conflicting with the image's quality. This means that if the sensitivity increases, the image's quality decreases, on the contrary, if the image's quality increases, the sensitivity decreases. In order to get better image quality, #15 value should decrease 30% ~ 50%.

The above is the effect of 1/f noise in the system's NEFD, besides that, 1/f noise also affects the system's detection

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performance. When the infrared imaging system is used in the guidance or detection system, it will face many point target detection problems. In fact the infrared system sensitivity relates to the performance of point target detection. In the serial scanning system, the noise model being used is Gaussian noise, it is the noise model in which the white noise passes the band pass filter. The detection difficulty is small, it is easy to detect. In the parallel scanning system, the noise model is the Gaussian model in which the colored noise (1/f noise) passes narrow band filter. The point target detection difficulty is big, being compared with the former one. It needs to enhance signal to noise ratio or prolong the processing time, it means the system's detection sensitivity decreases. It is needed to study further the effect of 1/f noise on the detection

sensitivity to process quantitative computing. From the practical results of some institutes, we can see that this effect is relatively big.

1.3 The effect of cold baffle

When the sensor's performance reaches the background limitation, its D^* value relates to the sensor's cold baffle, the computation formula is shown as following:

$$D^*(\theta) = \frac{D^*(\pi)}{\sin(\frac{\theta}{2})}$$

$D^*(\pi)$ is the value without cold baffle, θ is the cold baffle's equivalent conic angle. $D^*(\theta)$ is D^* when the cold baffle angle is θ, it is the actual D^* value of the sensor with cold baffle. We can see that, the smaller the cold baffle angle, the bigger the value of D^*. The sensor's cold baffle angle being used in the infrared system usually should be equal to or larger than the aperture angle of the optical system, otherwise the effective aperture of the optical system will decrease. So when the sensor's cold baffle angle is equal to the optical aperture angle, D^* value reaches its peak, the whole system will have good performance.

As for the multiple unit sensor, when only one cold baffle is used, almost each detection unit has different cold baffle angle. In order to keep that the minimum cold baffle angle of one specific detection unit is equal to the optical aperture angle, it will cause the cold baffle angles of most of the detection units to be larger than the optical aperture angle. Through the geometrical relationship analysis we can see that the bigger the length to width ratio of multiple detection unit distribution, the larger the equivalent cold baffle angle. On the other hand, the more the multiple detection units distribution is close to a circle (square), the more is the equivalent cold baffle angle close to the optical system's

aperture angle.

The cold baffle is shown in figure 3.

From the figure we can see that, θ_0 value of the serial scanning is smaller than that of the parallel scanning, it means that the cold baffle effect is better. With the increase of h, the difference of these two scheme's cold baffle effect will decrease. But the increase of h is limited by the structure size of the sensor and the refrigeration power loss, h value can be too big. So for the multiple unit line array sensor, its cold baffle efficiency is low, the refrigeration effect is poorer than that of the serial scanning. Due to the difference of the cold baffle efficiency, D^* value of the parallel scanning sensor is smaller than that of the serial scanning sensor. It needs to be emphasized that equation (6) is founded on the condition that the sensor reaches the background limitation, at this time the proportion of 1/f noise is very small, it can be ignored in the sensor's total noise. In other words, the effects of the 1/f noise and the cold baffle on the actual D^* value in the sensors with different scanning schemes are not completely independent. If the effect of 1/f noise is big, the effect of the cold baffle will decrease, on the contrary, if the effect of 1/f noise is small, the effect of the cold baffle will increase.

1.4 The effect of the multiple unit sensor's heterogeneity

Due to the material and technical factors, the multiple unit infrared sensor has fairly severe heterogeneity, for example, for the multiple unit long wave PC.MCT sensor, the deviation of D^* values of its poor unit and good unit and sensor's average value of $\overline{D^*}$ is 10% ~ 20%, or even bigger.

For the parallel scanning scheme, each detection unit of the multiple unit sensor scans part of the full viewing field, the performance of the full viewing field needs to degrade the performance of high performance units to accommodate the poor performance units, it means that the D^* value which is selected to compute the parallel scanning

system's sensitivity should be D^*_N (D^*_N is the software defect nominal value of the sensor).

In the serial scanning scheme, each detection unit of the multiple unit sensor scans a full viewing field, the multiple unit characteristic is gained by accumulation processing.

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Its equivalent unit D* value is shown by the following equation:

$$D^* = D^*_{RMS} = \sqrt{\frac{\sum D_i^{*2}}{N}}$$

$D^*_{RMS} > D^*_N$, when the heterogeneity of the multiple unit sensor is fairly big, D^*_{RMS} / D^*_N relatively big. Most of the domestic sensor manufacturers supply $\overline{D^*}$, values for the multiple unit sensor, as for the equivalent unit's D* value of the parallel scanning system, it should be less. Taking the multiple unit line array long wave PC.MCT sensor as example, D^*_N can only be 0.8 ~ 0.9 of $\overline{D^*}$, for the sensor with more units and poorer quality, it is even smaller. For the sensor of the serial scanning, its D^*_{RMS} is close to $\overline{D^*}$ value.

The effect of the heterogeneity on the D* can be described as: each unit of the serial scanning system's multiple unit sensor does its best, the good unit outperform the average, thus compensate for the poor unit in performance. But in the parallel scanning system, the poor unit acts as the standard, any unit is better than this standard will be used as just another standard unit.

Moreover, the size of the parallel scanning system's multiple unit line array sensor is large, for example, the line array size of a 180 unit sensor can be about 9mm; but for the serial scanning system, its sensor's size is about 1mm. It is obvious that due to the material's heterogeneity, not only the heterogeneity of the sensor's performance parameters of the former one is severer than that of the latter one, but also the performance itself is not as good as that of the latter one.

From the above analysis we can see that, due to the different scanning schemes that the optical mechanical scanning infrared system employs, there exists a difference between heterogeneity of the multiple unit sensors they use, and its effect on the system's performance. The serial scanning system is better than the parallel scanning system.

1.5 Conclusion of this section

From the above analysis we can see that, in the circumstance that the infrared sensors which are currently in use have a great deficiency, due to the effect of 1/f noise, cold baffle efficiency and the heterogeneity of the multiple unit sensor and other factors, the performance of the same type sensor being used in the different schemes system is very different. Taking the long wave PC.MCT sensor as example, with the same system parameter, the D* value of the serial scanning scheme is 2 or 3 times greater than that of the parallel scanning scheme. From the system sensitivity equation we can see that, a system with a value 2 - 3 times bigger in D* means the system has 4 - 9 times more sensor unit in equivalent. The experts of foreign countries said in their papers and references that, 20 unit serial scanning systems can reach the performance of 200 unit parallel scanning systems. Some experts said that, using 1/3 - 1/9 of the parallel scanning system's unit to construct the serial scanning system can achieve the same performance. The Honeywell Corporation of the US said that its 28 unit serial scanning system reaches the performance of 120, 180 unit general modules.

2. Imaging quality

As the imaging system, the imaging quality is the important performance of the system, but for the thermal imaging system the quantitative target of the imaging quality is not definite. Here we make a qualitative comparison referring to the visible light television.

The image quality of the television is measured by resolution, grey

scale and so on. The image quality of the television depends on its pass band characteristic, the wider is the pass band and the higher is the upper frequency limit, the higher is the resolution and clearer is the image's detail; the lower is the lower frequency limit, the more average is the image and the stronger ability does it have for larger and average images. (in the television system, the lower frequency limit is low enough, so it is not the factor that affects the image's quality. In most circumstances its effect can be ignored) Usually the pass band of the television is in the range from about 10Hz to 4 ~ 6 MHz.

If the ratio $(K_f = \frac{f_H}{f_L})$ of the system's pass band upper frequency to its lower frequency is used to qualitatively measure the image quality, (K_f) of the television can approximately reach 5×10^6. At this time the resolution of the television image is about 500 lines, the average and large background image of the full screen can really reappear.

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The concept of measuring the image quality of the infrared thermal imaging system is the same as that of the television. Analyzing by using this concept, the imaging quality difference of the different imaging systems is obvious. Under the condition that it is similar to the above mentioned television frame frequency, the bandwidth of the parallel scanning system is several kHz, its lower threshold frequency is several Hz ~ dozens Hz (reduce the lower threshold frequency, will increase the effect of 1/f noise and severely decreases the system's sensitivity), so the 10^3 value of the parallel scanning system is in 10's to 1000's order of magnitude. The bandwidth of the serial scanning system is about dozens of kHz ~ 1MHz, its lower threshold frequency is several Hz ~ dozens Hz, K_f, value is in $10^4 \sim 10^6$ magnitude order. It is obvious that the image quality of the serial scanning system is better than that of the parallel scanning system.

When comparing the product performance between the serial scanning

system and the parallel scanning system, The Honeywell Corporation of the US said something about the imaging quality: for the parallel scanning system, when the complexity of its alternate coupling circuit is maintained in a reasonable range (the lower threshold frequency can not be too low), the average thermal radiation of the viewing field changes, it causes an unperfected re-display of the image; another effect is the over modulation and blurred image because of the poor low frequency response, the result of this kind of effect is that it is very difficult to display high temperature targets. For the serial scanning system, when it displays the high temperature targets, it does not make the visual frequency information blurred, displaying the hot target is its intrinsic ability. Because of its high scanning speed, it does not cause over modulation for the fixed low frequency response. These factors ensure that the image quality of the serial scanning system is very good. For the anti-aircraft application, it is important to re-display the actual image around the high temperature target, the image of its neighboring moving targets should not be annihilated by other hot objects such as boosting rocket, airplane engine, decoy or high temperature aircraft. The serial scanning system is more suitable for this demand than the parallel scanning system.

In addition, with regards to the local homogeneity and deficiency of the image, the difference of these two scanning schemes is obvious: for the parallel scanning system which employs PC.MCT multiple unit line array sensor, its hardware defect (blind unit) is about 4% (US army standard is below 4%), there are 2 ~ 3 blind units in the 60 unit sensor, and for 180 unit sensor there are about 7 blind units. Each blind unit will cause one (or two) black (or white, without image) line in the image. Besides, due to the heterogeneity of the detection unit, such as the heterogeneity of the optical spectrum response, 1/f noise, there exists stripe background luminance difference, it causes a stripe and false display in the image and reduces the image quality. Being compared with the parallel scanning

system, each detection unit of the serial scanning system scans the whole viewing field, the image is the average synthetic result of many detection units, so its image is homogeneous.

To sum up, there exists fairly large difference between the imaging quality and image homogeneity between these two kinds of schemes, the serial scanning system is better than the parallel scanning system.

3. The related technologies, cost and production feasibility

As the above mentioned, in the circumstance that there still exists deficiency in the current sensors, to obtain the same thermal imaging system performance, the detection unit number of the serial scanning system only needs to be 1/3 ~ 1/9 of that of the parallel scanning system, it means the serial scanning system is better than the parallel scanning system with regard to the related technologies.

The simplified table of the comparison between Honeywell's MK II (2 * 14 serial scanning) of the US and the general modules (120, 180 units parallel scanning) is shown below:

	serial scanning	parallel scanning
#6 size	1/15	basic size
refrigeration power	1/4	1W
sensor's lens	1 piece	about 3 pieces*
preceding optical display system	optimum	too large (pupil drifting)

*extreme wide instantaneous viewing field in the vertical direction

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In addition, the number of electric devices and modules of the serial scanning system is far less than that of the parallel scanning system; the detection unit of the serial scanning is in the redundant status; the offset and gain of the multiple channels does not need adjustment, it greatly reduces the number of the adjusting point and devices and modules. All these factors mean that the electric system of the serial scanning system is simple and dependable.

As an infrared imaging system, the infrared sensor is one of the high cost components. The production cost and production feasibility of the infrared sensor relate to the vitality of the whole system. As mentioned above, the line size of the parallel scanning system's large line array infrared sensor is about 9mm, for the sensor of the serial scanning system which has corresponding performance, its line size is only about 1mm. There exists a big difference between these two scanning scheme systems, not only of their chip areas, but also of the sensor's chip cost. Some materials of domestic manufacturers show that the good finished product rate of the former one is 20%, the good finished product rate of the latter one is 80%. So, the ratio of the two scheme's sensor chip amount which can be produced in material of the same size can reach

dozens of times. It is obvious that the cost and production feasibility of the serial scanning sensor is better than that of the parallel scanning sensor.

4. Conclusion

The performance and quality of the infrared system generally are measured by the unit amount of the infrared sensor. (it is correct for the same infrared system of the same scheme, or for the future developing trend when the infrared system will employ a perfect sensor) But this point of view is only one-sided. From the analysis in this paper, it is clear that, in the current circumstance that sensors being used still have a deficiency, for the optical mechanical scanning infrared imaging system, the effect of the scanning scheme on the system performance and quality is more remarkable than that of the number of sensor units. The serial scanning system of less units can obtain better performance and quality than the parallel scanning system of more units. This means, the infrared imaging system of more units is not guaranteed to be better than the system of less units.

From the comparison of the two schemes we can see that, the serial scanning scheme is better than the parallel scanning scheme with regards to the system sensitivity, imaging quality, related technologies, cost and production feasibility. When we design and choose the optical mechanical scanning infrared imaging system, we should consider the scanning scheme as an important factor. As for the product planning, more attention should be paid to the selection of scanning scheme.

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The Laser Weapon Development State in Foreign Countries

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Keyword: Directed energy weapon, laser weapon, laser blinding weapon, tactical air defense laser weapon, airborne laser weapon, laser directive interference

1. Introduction

Currently, the US, Russia, Germany, France, Britain are all actively developing laser weapons of different usages, where research in the US is most advanced, its category is complete, the laser weapons used for the battle field are more and more mature. Some laser interference and laser blinding weapons projects have finished research and development stage, and begin to equip the arm forces. The research and development work of tactical air defense laser weapons has gained a series of important advancements; The army, navy and air force of the US has processed cycles of researching, designing, producing, installing, and testing for several times; has tested its technical feasibility and engineering feasibility in several real war emulating experiments, there is no existing technical difficulty. Currently, they are solving the problems of installation in all kinds of platforms, and working on problems in all kinds of field operation conditions, making great efforts to enhance the performance of maneuverability, reliability, long term storage, and simplify the operation. From the current developing state, we can say that before year 2000, it can

reach the level that according to the real war needs, these weapons can be produced and equip armies immediately. In order to intercept the ballistic missile in its active flying period, the US air force is developing the airborne laser weapon. Its research and developing work has been in full speed, the air force calls it a "deployable" device. Two contractors both said that there is no technical difficulty existing, the main task is to solve the engineering problem and system overall design problem. The US Ballistic Missile Defense Bureau is supporting the strategic defense laser weapon development now.

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2. Laser blinding weapon has equipped the arm forces

The US, Russia, Britain and Germany are all actively developing low energy laser weapons. As early as in the war over Falkland Islands, British used simply laser blinding devices, and obtained some success. As reported in the references, there are 9 models currently being developed in the US, according to incomplete statistics, where the army is responsible for: "Stingray", "PZQ-5", "Jaguar", #2 , #3 , "Cobra", the air force is responsible for: #4 , #5 , the navy is responsible for: MATES multiple waveband anti-warship electronic war system, etc. Among all those models, "Stingray" has an equipped army, PLQ-5 is about to equip the army.

2.1 The laser blinding weapon that equipped the US army - "Stingray"

"Stingray" began developing in 1982, was planned to be installed in the Bradley tank. Its laser output energy is more than 0.1 Joule, can destroy the optical and electronic sensor of 8 Km range, and damage human eyes even further (especially when people are surveying with periscopes or binoculars). This weapon system is equipped with wide viewing field searching and scanning device, the artilleryman can

locate several tanks or armor vehicles at the same time, and emit lasers to blind their optical and electronic sensors, make them blind and lose maneuverability. The demonstration prototype of this weapon system shows that it can obviously enhance the survival ability and fighting ability of Bradley tank. This system entered full scale engineering research and developing stage in July, 1991, it is predicted that from 1995, 164 of this system will be produced, and equip the M-3 Bradley tank. In the Gulf war period, the US army shipped two prototypes of "Stingray" laser blinding weapons to the battle field, deployed them to attend "desert storm" action, but because the ground war finished too soon, they were not used in the real war.

2.2 The US army will be equipped with PLQ-5 laser gun

Produced by Lockheed Thunders Corporation, PLQ-5 laser confrontation weapon is possibly the earliest laser weapon that the US army uses in large numbers in the battle field. The army plans to equip each company with 9 sets of flashlight pump solid laser device, equip each reconnaissance vehicle with one set. In the infantry, this kind of device will on the M-16 rifle, the solider will carry its power supply on his back. This kind of weapon has the function of temporarily blinding human eyes, and damaging optical sensor. There exists a plan to improve this weapon, adding ranging and other functions.

3. The high energy laser system experiment equipment of the US --- HELSTF

HELSTF is the most complete integrated laser weapon system experimental equipment now. Its structure diagram is shown in figure 1. The building cost of the whole experiment system is more than 800 million dollars. In addition to the continuing laser weapon experiment, this set of equipment will be open to the industry, academia, and universities, carry on the research tasks of astrophysics, material science, and

environmental protection, etc. The equipment's running cost of each experiment is 930 dollars, laser energy per million Joule costs 1440 dollars. There were some relatively systematic reports of HELSTF in succession in 93 ~ 94. The following is the simple introduction.

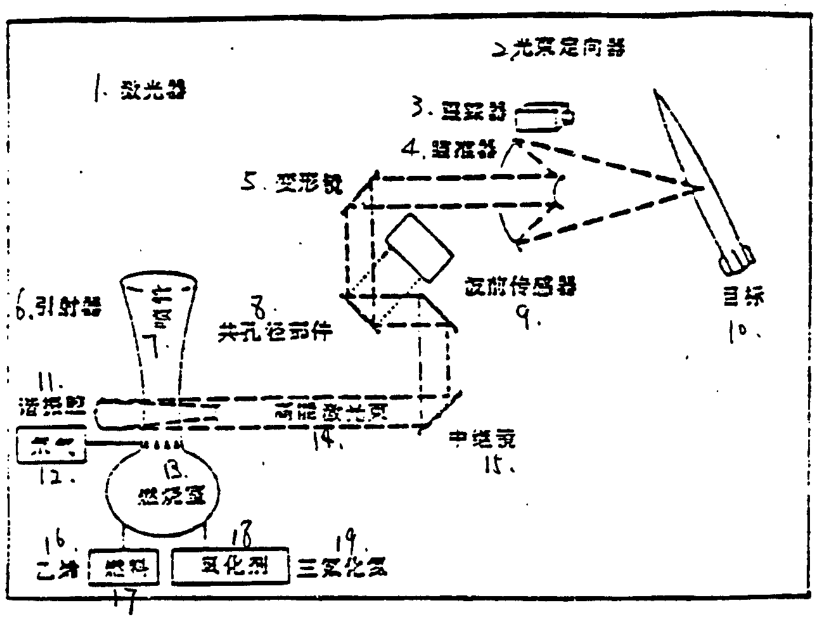

Figure 1. High energy laser weapon system

Key: 1. laser device 2. light beam directing device
3. tracking device 4. collimator 5. transformation device
6. inducing emitting device 7. nozzle 8. aperture unit
9. wave front sensor 10. target 11. cavity resonator 12. deuterium 13. combustion chamber 14. high energy laser beam
15. relaying mirror 16. ethylene 17. fuel 18. oxidant
19. NF3

3.1 Medium infrared advanced chemistry laser device

The medium infrared advanced chemistry laser device (MIRACL) was produced by TRW Corporation for the navy as a technology and engineering development plan in the late 70's. The basic experimental laser device was first developed, then the Navy Advanced Chemistry Laser device (NACL) was developed, the medium infrared advanced chemistry laser device was the first million Watt level continuous wave chemistry laser device in the world. It is a deuterium fluoride chemistry laser device, its spectrum line distributes between wave lengths from 3.6 to 4.0 micron and occupies about 10 spectrum lines. After its first emitting laser in 1980, this laser device's accumulated emitting laser time is more than 2000 seconds. In 1984, this laser device was moved from TRW

Corporation to the high energy laser system experimental equipment.

MIRACL is similar to the rocket engine, all use fuel (ethylene C_2H_4) and oxidant (NF_3) for combustion. The free fluorine atoms in their excitation state are one kind of the combustion product. In the downstream part adjacent to the combustion chamber, deuterium and helium are injected into the main air stream. Deuterium and fluorine in the excitation state combine together to produce a deuterium fluoride (DF) molecule that is in the excitation state, at the same time, helium has the function of stabilizing the reaction and controlling the temperature. The direction of the laser device's cavity resonator is vertical to the main air stream direction, extracts optical energy. The optical cavity uses the active cooling method, it can work till the fuel is gone. Through changing the flow speed of the fuel and mixing, the laser device's output power can reduce from the full power to 13% the full power. The optical cavity pressure of the cavity resonator is 30 ba. After the waste gas passes the laser cavity resonator it goes into two square pressure expansion devices, in here the pressure of waste gas is recovered to 200 ba, then, the waste gas passes two 100 meters long steam inducing emitting devices, its pressure is recovered to the atmospheric pressure. At last, the gas is cleansed, using a large amount of clean water to spray and clean the high temperature gas at a flow rate of 40 Kg/sec. The remaining gas is diffused by the chimney, and in the very short distance it reaches the safety standard.

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In the light path between the optical cavity and light beam directing device, there are 10 water cooled reflecting mirrors. They cause reflection among the concave and convex cavity resonator mirrors in the optical cavity, these cavity mirrors are placed confocal, as the non-stable cavity structure. The output mirror in the optical cavity that is

placed #2 angle respect to the optical axis is utilized to realize the output coupling of optical energy. Then, the laser beam is reflected and passes a light beam shaping telescope that is made up of three units, thus the laser beam matches the input of the "Seastone" laser beam directing device (SLBD), then passes a pneumatic window, the laser beam that comes from the optical cavity of 30 ba cavity pressure emits into the atmosphere.

The low diffraction efficiency line grating on the relaying mirror is used to extract a small amount of the sample light beam among the MIRACL light beams, then make them pass into the light beam diagnosis device and the angle surveying sensor which is used for light beam automatic collimating. Two four-quadrant detectors are used for angle surveying, one of them is used to survey the MIRACL light beam, another is used to survey the helium neon directing light beam. The detector also surveys the collimation of the light beam that transfers from light beam directing device to isolating tower, and drives the control reflecting mirror which is placed on the base of the SLBD tower, makes the high energy laser beam enter SLBD collimately. Using this method one can make sure that the whole light beam is collimated from one end to another.

3.2 "Seastone" light beam directing device

"Seastone" light beam directing device has a beam expansion telescope which is installed on the constant-level shelf, its diameter is 1.8 meter. It uses an ordinary constant-level shelf to aim and provide a wide angle covering area, this shelf is used for pitch control of the light beam. Several relaying reflecting mirrors are used to make the high energy laser beam pass the light beam directing device according to some specific course. The Cassegrain reflecting beam expansion device which is installed on the constant-level shelf can expand the light beam so that the outer diameter is 1.5 meter. According to the different target distances, the

secondary lens in the beam expansion device is moved axially, thus the light beam can focus into a small spot at the target distance.

All relaying reflecting mirrors and the secondary lens in the light beam expansion device of the high energy laser light course employ the water cooling method. Because the power density of the high energy expanded laser beam which irradiates to the larger reflecting mirror is relatively low, the main mirror of the light beam expansion device need no water cooling system. The main mirror employs a light material design, uses low thermal expansion glass. The dry nitrogen flows along the axial direction of the high energy laser beam light course, thus in the light beam directing device, it can reduce the distortion, which is because the air is heated by the high energy light beam. The air stream of the air curtain crosswise passes the exit aperture of the light beam expansion mirror. It is convenient for the smooth transition between the axial direction inside adjusting air stream and the outer atmosphere, also it can avoid inhaling outer air into the light beam directing device.

"Seastone" light beam directing device uses the imaging sensor installed on the pitch constant-level shelf, it uses one controlling reflecting mirror to survey the target. The main sensor is a forward looking infrared system whose wave length is 8 ~ 11. 5 micron, and equipped with a telescope whose diameter is 40 centimeter. The heart shape tracking with space gate and the correlation tracking algorithm are employed to reduce the background noise as much as possible when tracking the target.

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3.3 The integrated system experiment

3.3. 1 High power experiment with a static target

In the period from May to August 1986, In HELSTF, using the integrated MIRACL / SLBD, carried out the first light beam

control experiment. In order to reduce the heat damage of SLBD's un-cooled devices, which is due to the inaccuracy of the MIRACL light beam's direction, as much as possible, in the experiment of 8 firings, the emitting power and persistent irradiating time increased step by step, till reaching the goal of whole power and persistent time of 10 seconds.

3.3.2 Low power experiment with a flying target

In the period from February to August 1987, in HELSTF, the tracking experiments of the airplane were done, it was used to evaluate the SLBD's ability of aiming and tracking a flying target. In those experiments, the low power visible laser beam replaced MIRACL light beam. A krypton ion laser device (wavelength is 0.647 micron) was placed on the base of SLBD. Using a control reflecting mirror, the laser was collimated to the input of SLBD, this method is the same as MIRACL light beam collimation method which is used in the high power experiment. From then on, there were totally three times low power experiments.

In the first experiment, a UH-1 helicopter which was equipped with a tracking source was used, the recording sensor of light beam to the target which was developed by Johns Hopkins Application Physics Laboratory was also used. The second low power experiment used an airplane target to evaluate the radar signal interface between White Sand shooting range and SLBD. The third experiment used BQM-34 "Fire Wasp" unmanned target plane, the flying speed of this target plane is 400 knots, at the distance of 3 kilometers, it flew crosswise. It was used to evaluate the SLBD's ability of target capturing, signal interfacing, accurate tracking and revising the aiming point error.

3.3.3 The high power experiment with a flying target

In those experiments, SLBD captured and tracked BQM-34 "Fire Wasp" unmanned target plane, and focused the high power MIRACL light beam at a predetermined target aiming point. The unmanned target plane is equipped with the flying target array

(FTA) which was designed by Scientific Application National Defense Corporation. The target array is made up of 696 thermocouple sensor matrixes, these sensors can endure several seconds irradiation of high power laser. These experiments directly surveyed the fluctuation of the light beam on the target, the error and drift of required aiming point, focusing quality of light beam and the atmosphere transmission effect. These surveying data can be used to improve the system's performance and support the computer simulation.

3.3.4 Dynamic antipersonnel power experiment

In 1987 and 1989, supported by the "Balance Technology Initiation" (BTI), MIRACL/ SLBD system was used for the antipersonnel power experiments. These experiments and the performance which was predicted were on the basis of the aiming experiments which were done before and by the flying target array in BQM-34 "Fire Wasp" target plane. In the experiment of 1987, a subsonic BQM-34 "Fire Wasp" target plane which flew crosswise the laser experiment field was successfully tracked and destroyed. When the distance doubled, and the experiment was repeated,

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it also succeeded. In these two experiments, the damage caused by the MIRACL light beam and the phenomenon appeared in the unmanned target plane proved the prediction very well. For the first time, these experiments completely proved that the antipersonnel power models for the flying target are correct. These models are on the basis of the static experiment in many years and the damaged missile loci computer analysis.

In the spring of 1989, MIRACL / SLBD system was used to intercept an ultrasonic "VANDAL" missile. This missile is the improved model of "TALOS" surface-to-air missile, it is equipped with a ramjet engine with a maximum speed of Mach 2. Its size is large, weight is heavy. It is the target that any

air defense system hardly can deal with. In the experiment, VANDAL missile was required to fly over the laser experiment field of low altitude, maximum speed and crosswise flight, it simulated a ultrasonic cruise missile attacking a target that is near the laser system. When a VANDAL missile was launched from the launching platform which was several miles away from the laser experiment field, it was tracked immediately by the ranging radar. When the VANDAL missile was approaching, the radar signal which was obtained by the ranging radar transferred to the infrared tracking device of SLBD. In the experiment, when the target was still far from the allowed shooting window, SLBD had captured this target. As soon as VANDAL entered the allowed shooting window, the MIRACL laser was fired immediately, in a short time, the missile was totally damaged. This experiment convincingly demonstrated and proved that high energy can destroy anti-warship missiles. The performance of MIRACL/SLBD was very close to the prediction before the experiment. It fully demonstrated the use of high energy laser systems in a tactical circumstance.

3.3.5 High altitude accurate aiming experiment

In December 1988, MIRACL/SLBD system was decided to be upgraded, in order to study the technology and engineering problems which are related to the accurate tracking and high energy laser beam aiming from ground to high altitude or space. The main purpose of the upgrade was to enhance the sensitivity, accuracy and bandwidth of SLBD tracking system, to make the SLBD aperture track the target through the beam expansion device when emitting laser. Thus the tracking device can aim along the aiming line direction of a MIRACL light beam. Former tracking devices were placed in the outside of the beam expansion device, and aimed the target along different aiming lines. The main technical improvement required by this plan was to employ optical duplexes, it can isolate very weak echo device tracking signals from the high energy laser beam which emitted outward.

After finishing the improvement, in order to test its performance, a series of experiments were done. The first experiment was done in February 1991, the stars were used as tracking source, the experiments provided the chance to evaluate all kinds of tracking technologies. The experiment and demonstration proved the ability of wide band and wide whole aperture tracking under the existing high energy light beam. In the experiment, there was no phenomenon of losing tracking and unstable tracking. The output power level of MIRACL varied in the area of 3:1, for the purpose of data collecting and using the laser of different energy levels to irradiate new optical devices.

The second experiment was done in the same year in June. In the experiment, for the first time, an unmanned plane which was equipped with special equipment was used, the flying altitude of the plane was 13 kilometer. This kind of High Altitude Target System (HATS) was designed to accurately and quickly survey the intensity distribution of high focused high energy laser beams, and utilize the remote surveying transmitter

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to transmit data to the recording system in HELSTF. This unmanned plane successfully took off, but due to the tracking device's problem, accurate tracking was not accomplished.

The third experiment was done in the same year in August, also using a High Altitude Target System (HATS). The object of this experiment was to demonstrate and test the accurate tracking and aiming ability of MIRACL light beam, so as to further study the interference effect of MIRACL light beams on the accurate tracking devices. The experiment was very successful. Earlier experiments showed that there were some tracking interference problems existing which were due to the high energy laser. This experiment showed that those problems had been solved. At the point that was very near the

predetermined aiming point, a stable and perfectly focused high energy laser beam was detected.

The fourth experiment which used a High Altitude Target System was done in the same year in October, it was also the last experiment. The object of this experiment was to demonstrate and prove that the MIRACL light beam had the tracking and aiming ability which was stable, accurate and long term; demonstrate and prove the collimation technology of high energy laser beams; and evaluate the light beam aiming technology which can aim and lock the high energy laser beam at the target. Similarly, this experiment also reached all main experiment objects, obtained the previously expected performance.

4. The US navy warship carrying air defense laser weapons

The TRW Corporation of the US is cooperating with several departments of the US navy, drafting a warship carrying laser air defense weapon plans which further utilizes currently existing technology, makes the system design modularization. The required basic principles of this high energy laser weapon system (HELWS) design are:

a. provide the laser energy output which is equivalent to the current MIRACL/SLBD, use modularization design principle.

b. its design must be on the basis of currently existing MIRACL/SLBD, at the same time, only proved technologies could be employed.

c. it must reduce its effect on other warship carrying systems as much as possible.

d. the design must accord with normal environmental requirements.

e. the system design need only meet the application requirements, need not consider unnecessary technical advantages and make the design requirement too high.

HELWS design and effect analysis has been finished. Some

key points of the design scheme include: selecting 51# rib of CG-53 warship as the installation space for HELWS; employing gas turbine engine pressure recovery system, greatly decreasing the volume of the laser system, it is an important improvement in engineering; using wired rib, compound structure, high pressure can, the weight, length and diameter of each can is equivalent to the weight, length and diameter of a "Tomahawk" missile shipping case in the vertical launching system; the light beam directing device uses fluorine glass window, has very good waterproof capacity, is more feasible than SLBD. Because the laser power comes from the chemical energy of fuel, the needed electrical power of the whole weapon system is: maintaining power 130 Kilowatt, running power 390 Kilowatt.

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A final analysis of the high energy laser weapon system gained cooperation and recognition of Navy Sea System Headquarters (NavSea). The high energy weapon system will be installed in the volume which is equivalent to the Mark45 model 5 inch / 54 warship artillery system and its ammunition storeroom, compared with the warship artillery system, the weight of HELWS reduces 15%. The new weight distribution in this design also reduces 5% of the capsize moment. This HELWS is a system of low risk. It has been demonstrated and proved that, acting as a effective weapon, it has a casualty probability near 1.

Currently, the US navy is demonstrating and proving the feasibility of beginning warships carrying high energy laser weapon system demonstration experiments on warship in 1995, and considering installing this modularized system in the warship.

5. The tactical anti-missile laser weapon system of the US army

On the basis of its laser weapon technology development, TRW Corporation of the US designed a front line mobile defense system for the US army, it was called a "general area defense integrated anti-missile" (Gardian) laser weapon system, the purpose was to offset the inadequacy of the medium range anti-missile system and long range anti-missile system of the army. It can equip wheeled or belted armor vehicles and is used to cope with the low altitude attacking stealth target which is at a range of 10 kilometers. This kind of weapon has a killing precision of 100%, which is an impossible mission for the traditional guided missile.

This system is made up of a 400 kilowatt deuterium fluoride high energy laser device and a 70 centimeter diameter directing device/tracking device. The responding time of this system is about 1 second, emitting rate is 20 ~ 50 times/minute, the emitting cost is about 1000 dollars/time. This system is designed to intercept the mobile target whose gravitation acceleration overload is 100g, moreover, as soon as it locks on the target, it can irradiate the target using a laser till the target is destroyed. The smoke, haze and other air streams in the battle field will not produce the thermal blooming which affects the laser beam's quality. The vile weather condition will at most make the necessary laser irradiation time of killing the target 0.1 second longer than 1 second which is the necessary time for clear weather.

TRW Corporation said that, since the first experiment of this system in 1977, its killing probability was 100%. Some research of this kind of system showed that: the required power of ground force laser weapon systems can be between 100 kilowatt and 1000 kilowatt, and for the front line mobile defense application, the required power is about 500 kilowatt. It was reported that this weapon system can severely destroy the radar cowl of the guided missile target 4 kilometer away, and also can severely damage the optical system 10 kilometers away. According to the current scheme, in order to cover a

war zone, about 2 to 4 "general area defense integrated anti-missile" laser weapon systems should be deployed.

6. The US army is actively developing airborne laser weapons

The war zone defense airborne laser anti-missile weapon can destroy the war zone ballistic missile in its booster flying period, and make the debris of the missile which carries nuclear, biological and chemical warheads fall onto the enemy area, thus terrorize the enemy and make attackers give up their actions.

In the area of war zone defense, the US air force is implementing a plan of airborne anti-missile weapon demonstration and test, the device they employ is oxygen iodine chemical laser device. The US army is actively developing unmanned airborne war zone defense

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laser weapons, the device they employed is the diode pump solid laser device.

6.1 The US air force begins to implement the war zone airborne anti-missile weapon plan

After the "Gulf war", in order to cope with the Scud missile, the US national defense nuclear energy office did a research project named "desert flash" using the fund provided by the Strategic Defense Initiation. This research project was to compare the models of "Patriot" surface-to-air missile and the airborne laser weapon. Because the airborne laser weapon can intercept the missile in its active flying stage, and the terrain and weather conditions are suitable for the airborne laser weapon, the scheme of using the airborne laser weapon to intercept Scud missile was confirmed. The airborne laser weapon brought the attention of the US air force air fighting headquarters. In 1992, the US air force performed airborne laser long range transmission experiments. These experiments are the key to determining the battle capacity of

the airborne laser weapon.

In June 30, 1993, the US air force officially invited public bidding for the implementation of airborne laser anti-missile demonstration and test plan, prepared to spend 8 years, invest 800 million dollars, produce and test the "deployable prototype" of this weapon, thus test the necessary technologies of using laser weapons to capture, track and destroy the war zone ballistic guided missile which is in its boosting flying period and range is 120 ~ 3000 kilometer.

The influence of high altitude turbulent flow on the laser beam is the main problem of airborne laser weapon. In February 1994, the initial flying experiment was done in Montana, the purpose was to determine whether to use adaptive optics in the airborne laser weapon to compensate for turbulent flow. The conclusion of the experiment was: "the performance of the adaptive optics system is not severely limited by the high altitude turbulent flow". This conclusion was inspiring. The purpose of the experiment in March 1994 was mainly to study the turbulent flow on the top of the troposphere. In the experiment, the distance between the two airplanes changed from 23 kilometer to 211 kilometer, most of the data were collected when the distance between two planes was 100 ~ 200 kilometer.

According to the plan of the US air force, the initial scheme of airborne laser weapon systems was: using passive infrared sensors to survey the target, using high power chemical laser device to destroy the target, integrated with battle management, commanding, control and communication, installed the system in a Boeing 747 wide airframe plane, thus making up a complete war system. In the local war where the US army engages and is threatened by the ballistic guided missile, this plane will fly to the war zone, as soon as it finds the target, it will fire laser beams to intercept and destroy the offense target. It is said that in order to implement missile boosting period intercepting, the effective

range of the laser weapon is required to be more than 400 kilometers, moreover, it should be able to continuously fire in a very short time and attack several targets.

In 1993, two corporation groups formally presented the schemes of their own to the Air Force. One group was headed by Boeing Corporation, including TRW Corporation and Lockheed Corporation; another group was headed by Rockwell Corporation, including E-System Corporation and Huges Plane Corporation and etc. They all employed oxygen iodine chemical laser devices. The army has granted the "dual scheme" design contract to both groups, each contract worth 2.1 million dollars. When delegates of these two groups signed the contract, they all mentioned that they got support from the long distance transmission experiment result. These two groups will compete, in 1997, one of them will be selected as the main contractor and enter the demonstration and test stage, this group will be in charge of developing demonstration prototype system. At the end of this century, the experiment of intercepting boosting period ballistic missile will be done, in the beginning of next century, the purchase issues will be considered.

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It is said that this plan has no significant technical difficulty, only some engineering problems need to be solved.

6.2 The unmanned airborne war zone defense laser weapon scheme of the US army

The US army is actively developing an unmanned airborne laser weapon coded "Defender's Glory". This scheme is on the basis of the advanced laser research in Lawrence Livermore laboratory. It is said that this kind of laser weapon can shoot down "Scud" missiles as far as 145 kilometers away. It provides the weapon system to the ground force that can eliminate the threat of war zone ballistic missiles.

The army thinks that, compared with the manned plane, the

unmanned plane has the following advantages: in the relative high altitude that the unmanned plane flies, the atmosphere is thin, the laser's transmission efficiency is higher and killing is more effective. The production cost and maintaining cost of the unmanned plane is also lower than that of the manned plane, and there is no risk to any lives.

The miniature solid laser device of the Lawrence Livermore Laboratory which is used for onboard small or unmanned planes has obtained an important breakthrough. In July 1992, they developed a mini solid laser device whose volume is smaller than a grapefruit, output power is 1000 watt, working wave length is 1.06 micron. This research achievement is the important milestone of laser weapon technology research and development. This laser device employs advanced solid laser diode pump and micro channel cooling method, efficiency is very high, weight is very light, volume is very small. It is reported that Russians agreed to sell advanced related laser technology to this laboratory, with their technical help, this laboratory will greatly increase its laser device's power from current 1000 watt to several million watt, it is enough to make this laser device as a effective, airborne laser weapon.

7. The US Ballistic Missile Defense Office supports the development of strategic defense space based laser weapon

The space based "Alpha" chemical laser device plan was managed and implemented by former Strategic Defense Initiation Office (SDIO), now it is supported by Ballistic Missile Defense Office (BMDO), it is a directed energy weapon plan. In 1993 the US National Defense Department emphasized that, deploying "Alpha" chemical laser weapon in space can deal with worldwide threatens which possibly increases constantly and is caused by the ballistic missile carrying chemical and biologic war head. Also it said that, "if there is enough financial and political support", in 7 years, it can start

space laser experiments, in 15 years, develop the chemical laser weapon which can be used as an anti-missile weapon. General Malcom O'Neill, the new chief of Ballistic Missile Defense Office said, they will continue develop this weapon as a "very good" candidate to destroy initial boosting stage war zone missile.

Currently, the hydrogen fluoride chemical laser device in this weapon system has gained high quality output laser beams when output power is several million watt. Several active controlling combined mirrors whose diameter are 4 meters have been developed, and can be enlarged to larger size. The current "Alpha/large scale advanced reflecting mirror plan experiment" is planned to begin high power experiment in the middle of 1996.

8. Conclusion

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Through the above depiction and analysis, we reach the following conclusions.

a. The laser weapon is the beginning of a completely new generation weapon

The earliest weapons of mankind are stones, sticks, bows and arrows; after the advancement of metallurgy, the broadsword, lance and other weapons appeared; after the mankind mastered the gunpowder, gun, artillery, and bomb and etc. Then came A-bomb, and H-bomb, etc., but these weapons can be viewed as the extension of gunpowder weapons. Currently, mankind is viewing the appearance of the directed energy weapons, the laser weapon will be the first developed weapon of the directed energy weapons, it is the inevitable trend of mankind's weapon development.

b. The appearance of the laser weapon is not the renewing of some kinds of weapons, it is the overall development from low energy laser weapon to high energy laser

weapon.

From current development, the weapons that already appeared or will appear include laser guns, laser interference weapons, laser blinding weapon, tactics air defense laser weapon, war zone airborne laser weapon, and strategic anti-missile laser weapon, etc.

c. The low energy laser weapons have been mature, they are used by with combat troops now.

d. The tactics air defense laser weapon is in its engineering development stage or equipment development stage, it is estimated that it will be used in the battle field at the beginning of the 21st century.

e. The war zone airborne laser anti-missile weapon has no technical difficulty now, the engineering problem is being solved.

f. The strategic laser weapon has a long way to go to implement, but it also in its advanced research stage.

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Space Rendezvous and Docking Navigation survey sensor

---- RVD laser radar survey system

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Abstract: The space docking compound laser radar survey sensor is a kind of combined optical survey sensor that organically combines the laser radar with CCD optical imaging sensor, thus finishes the medium and short range rendezvous and docking. The RVD compound laser radar was developed with the advancement of laser technology, imaging technology and high speed micro processing technology. It has strong points such as low power, small size, and light weight. These strong points can greatly enhance the survey precision and reliability of the space rendezvous and docking. So, RVD compound laser radar is one of the favorite schemes for space docking. This paper puts emphasis on the constitution, principle, key technology and resolving method of RVD laser radar.

Keyword: Diode semiconductor laser device, Laser scanning, Laser tracking, CCD goniometry, Image processing

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1. Introduction

1.1 Application background and needs

At the end of this century and beginning of the next century, our country will build permanent space station facilities in space; one of the key technologies that need to be solved is the space rendezvous and docking problem. In order to finish the space rendezvous and docking perfectly, it is necessary to accurately survey some data such as the relative distance, relative speed, relative attitude angle of

two spacecraft. Thus the survey sensor cannot be neglected, especially in order to reduce the dependence on the earth station and the astronaut, enhance the reliability, develop the independent rendezvous and docking technology of our own country, the high precision survey sensor is absoluteLY necessary. RVD compound laser radar survey sensor is a kind of combined optical survey sensor that organically combines the laser radar with CCD optical imaging sensor, thus finishes the medium and short range rendezvous and docking. The RVD compound laser radar was developed with the advancement of the laser technology, imaging technology and high speed micro processing technology. Because the laser's wavelength is short, monochromaticity is good, brightness is high, being compared with microwave radar, it has high distance resolution, angle resolution and velocity resolution; if the diode semiconductor laser device is employed as the emitter, it has the advantages of low power, small size, and light weight. These advantages of the laser radar can greatly enhance the survey precision and reliability of the space rendezvous and docking. Therefore, the RVD compound laser radar is one of the favorite schemes to enhance the RVD survey precision and reliability for the countries with advanced space technologies. Adopting the RVD compound laser radar is the inevitable development trend of the space docking technology. Practice has proved that, the model research must put emphasis on the key technologies, the researching of RVD compound laser radar should not be the job after Year 2000, it must begin with the research and development of the spaceship.

1.2 Mission and task

The basic task of the RVD compound laser radar is to finish the tracking spacecraft's precise tracking and surveying of the target spacecraft through the optical radar in the tracking spacecraft and the cooperative target in the target spacecraft, and provide the data on relative distance,

relative speed and relative gesture angle of these two spacecraft in real time.

1.3 Functions

In order to meet the demand of the mission and the task, also considering the special necessity of space, the RVD laser radar should have the following functions:

(1) The laser radar can accomplish the task of surveying the distance, angle and relatively short range pointing angle, CCD optical imaging sensor finishes the task, surveying the short range pointing angle.

(2) The laser radar and CCD optical imaging sensor can be the backup for each other to some extent.

(3) In the auto homing, terminal approaching stage, it should provide the data on the target spacecraft's distance and pointing to the computer in the tracking spacecraft center.

(4) It should have the ability of automatically monitoring and surveying, isolating the malfunction, ensuring the high reliability and high redundancy.

2. Tactical technology target

According to the task and demand of space docking, we think that with the current technology foundation and developing capability, if we select the suitable technology scheme, we can get the following overall tactical technology target.

1. 25Km - 300m

ranging precision: (1 ~ 5%) R

speed surveying precision: 0.1 m/s, (±50 m/s)

angle surveying precision: 0.4°, (±15°)

angle surveying speed precision: 0.006°/s, (±12° /s)

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2. 300 m ~ 10 m

ranging precision: (1 ~ 5%) R

speed surveying precision: 1 cm/s (v < 1m/s)

10 cm/s (v > 1m/s)

angle surveying precision: 0.5° (rolling angle < 180°)

0.1° (pitch angle and deviation angle < ±20°)

angular velocity precision: 0.002°/s (angular velocity ±1.2° /s)

3. scanning area: large viewing field is 20° x 20°

small viewing field is 3° x 3°

4. sampling rate: 10 Hz

3. Current technical state and developing trends in our country and other countries

3.1 Current technical state and developing trends in other countries

The space rendezvous and docking technology is the integration of several high technologies in space flight; the automate degree and reliability of the rendezvous and docking technology directly affects the degree that humans participate in the space operation and the construction scale of the earth survey and control net, moreover, the success and failure of the rendezvous and docking determines the success and failure of each space task, thus affecting the status of the space station system.

The surveying sensor system is one of the key technologies of the space rendezvous and docking. In the early stage, the US and the former Soviet Union all employed the microwave radar sensor to process RVD survey. The microwave radar has drawbacks such as large size, high power, low precision when it surveys in the approaching range; so when processing docking in the approaching range, the astronaut's eye for surveying and artificial docking scheme was employed. In order to process the real automated space rendezvous and docking, many countries developed high

precision surveying sensors.

In the late 50's, the successful development of the laser device made it possible to develop the laser radar which has very high surveying precision. The laser radar sensor system has features such as small size, light weight, high precision, and low power, besides, it is suitable for the whole process of the rendezvous and docking, so it was quickly employed in space flight. Currently, the US, Russia (former Soviet Union), Western Europe, Japan are all actively developing and researching. Among these countries, the Marshall Space Center of the US developed the first laser radar in the world which is used in the space rendezvous and docking, MBB Corporation of Germany developed the laser photoelectric sensor for the auto rendezvous and docking, Mitsubishi Electric Machine Corporation and Nippon Electricity Corporation (NEC) developed the laser radar which is used for tracking the rendezvous and docking.

Table 3.1 is the introduction of the RVD laser radar applications in foreign countries.

On the basis of the application and developing state of the space docking surveying technology and sensor in the US and the Soviet Union and other countries, we can clearly see that, (1) We should try our best to see that the auto space rendezvous and docking surveying technology is independent of the earth station, this scheme is not only economical, but also aims towards the high technology level. (2) The docking scheme, which employs the microwave radar for long range docking and the astronaut directly participates in the rendezvous and docking, has been tested by practical applications; (3) Being used in the rendezvous and docking surveying, the laser radar has the features of small size, low power, light weight, high precision, and can process auto rendezvous and docking, so it is the first choice for the future rendezvous and docking; (4) The whole process of auto rendezvous and docking covers a large area, from 100 Km to 0

m, so if only one kind of sensor is employed, it can not cover such a big task, thus the concept of the compound laser radar is introduced to finish the surveying task of the whole process.

3.2.3. Current technical state and developing trends in our country

Our country did more research on the microwave radar, laser radar and CCD sensor, but in the area of space docking surveying sensor field, our country's research is still somewhat blank.

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With the developing demand of our country's space technology, it is critical to present and specify the research scheme of RVD surveying technology that is suitable for our country's situation.

4. Key technologies

Table 3.1 The Summary of the application of laser radar RVD surveying in foreign countries

1.系统名称	2.研制时间	3.作用距离	4.工作方式
5 用于空间飞行器的激光雷达	6 美国马歇尔空中心(ITT公司)1967年第一样机,1971年第二代样机。	远距离 3～120km 近距离 0～3km 7	GaAs激光器为光源,析象管光电倍增管为接收器件,远距离为脉冲法测距,近距离为相位法测距,压电晶体驱动反射镜完成扫描,利用析象测量目标姿态。 8
9 用于空间飞行器的激光雷达	美国联合技术公司(Norden) 1978年完成样机。 10	根据作用距选择光源功率和反射器尺寸。 11	脉冲CO_2激光器为光源,高频HgCdTe探测器阵列为接收器件,检流计式扫描装置,外差式接收,在目标飞行器上安装一个特殊圆形对接目标,完成姿态测量。 12
激光对接系统 13	美国Johnson中心1986年报导。 14	远距离 22km～100m 近距离 100m～0m 15	CW半导体激光器为光源,光电二极管为接收器件,检流计式扫描装置,相位式测距,姿态测量由PDS和Wallaston棱镜完成。 16
多目标和单目定向敏感器 17	美国NASA1986年报导 18	多目标 100m～6m 单目标 6m～0m 19	析象管为接收器件,相位式测距,远距离用析象管测角。 20
RVD测量扫描激光雷达 21	日本东京宇航研究所 1987年报导。 22	远距离 20km～200m 近距离 200m～0m 23	CW半导体激光器作为光源,硅APD构成四象限检测器作为接收器件,利用相位法进行测距、姿态测量用CCD完成,采用检流计式扫描装置。 24
自主RVD测量光电敏感器 25	西德MBB公司 1985年报导 26	20km～接近 27	半导体激光器作为光源,硅APD为接收器件,检流计式扫描装置,姿态测量用CCD完成。 28
RVD测量跟踪激光雷达 29	日本电气,三菱公司, 30 1985年报导	30km～0.2m 近距离CCD成象 31	半导体激光器作光源,四象限检测器测角,CCD成象音频测距。 32
航天器载激光距离及距离变化率测定仪 33	西德MBB公司 1978年报导 34	250m～0m 35	共有三个激光器,连续,脉冲半导体激光器,CO_2连续激光器,硅APD、CCD和HgCdTe为接收器,CO_2激光器用于测速,脉冲激光器用于捕获目标,连续GaAlAs激光器用于测距。 36

See next page for Key to Table 3.1

1. System name 2. Developing time 3. Working range 4. Working mode

5. used for the laser radar in spacecraft

6. Marshall Space Center of the US (ITT Corporation), the first generation prototype in 1967, the second generation prototype in 1971

7. Long range, 3 ~ 120 Km, short range, 0 ~ 3 Km

8. GaAs laser device is used as a light source, image dissector and photoelectric multiplier tubes are used as receiving devices, pulse ranging for long range, phase ranging for short range, piezoelectricity transistor driving reflex mirror finishes scanning, image dissector is used to finish pointing surveying.

9. used for the laser radar in spacecraft

10. Norden Corporation of the US, the prototype was finished in 1978

11. selecting light source power and reverberator size according to the working range

12. Pulse CO2 laser device works as the light source, high frequency HgCdTe detector array works as receiving device, galvanometer scanning device, heterodyne receiver, install a special circular docking target in the target spacecraft to survey pointing.

13. Laser docking system 14. Reported by Johnson Space Center of the US in 1986

15. long range, 22 Km ~ 100 m, short range, 100 m ~ 0 m

16. CW semiconductor laser device works as light source, photoelectric diode works as receiving device, galvanometer scanning device, phase ranging, pointing surveying is done by PDS and Wallaston prism.

17. multiple targets and single target directional sensor

18. Reported by the US NASA in 1986

19. multiple targets, 100m ~ 6m, single target, 6m ~ 0m

20. image dissector works as receiving device, phase ranging, goniometer for long range uses image dissector.

21. RVD surveying scanning laser radar

22. Spaceflight Research Institute of Tokyo, Japan, reported in 1987

23. long range, 20Km ~ 200m, short range, 200m ~ 0m

24. CW semiconductor laser device works as light source, four quadrant detector which is made up by silicon APD works as receiving device, utilizing phase method to survey range, using CCD to survey pointing, galvanometer scanning device is employed

25. auto RVD surveying photoelectric sensor

26. MBB Corporation of Germany, reported in 1985

27. 20Km ~ approaching

28. Semiconductor laser device works as light source, silicon APD works as receiving device, galvanometer scanning device, pointing surveying is done by CCD

29. RVD surveying tracking laser radar

30. Mitsubishi Electric Machine Corporation and Nippon

Electricity Corporation, reported in 1985

31. 30 Km ~ 0.2 m short range CCD imaging

32. Semiconductor laser device works as light source, four quadrant detector surveys angle, CCD imaging audio frequency ranging

33. spaceborne laser range and range varying rate surveying device

34. MBB Corporation of Germany, reported in 1978

35. 250 m ~ 0 m

36. There are three laser devices, continuous, pulse semiconductor laser devices, CO_2 continuous laser device, Silicon APD, CCD and HgCdTe work as receiver, CO_2 laser device is used for speed surveying, pulse laser device is used to capture target, continuous GaAlAs laser device is used for ranging

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5. Technical Specification

5.1 System component

The process of rendezvous and docking can be approximately divided into earth guiding, auto homing, terminal approaching and docking on the initial aiming point. When considering the configuration scheme of the surveying sensor, we should consider the auto surveying of the relative distance and pointing of the two spacecraft, also should consider the surveying sensor system's redundancy, reliability, technology complexity and feasibility. With respect to the surveying range and surveying precision of RVD, it is difficult to rely on only one kind of sensor to finish the whole RVD surveying task, the compound laser radar which combines the laser radar with CCD optical sensor is introduced. For different range, there are different sensors to survey.

RVD compound laser radar is a kind of surveying system that is used for the high precision real time tracking. In order to reliably finish the capturing, tracking and real time surveying functions within the medium and short range, the following subsystems should be included in the whole system:

(1) laser tracking ranging radar sensor subsystem. (2) CCD optical sensor subsystem. (3) coordinated target subsystem. (4) data processing subsystem and detection subsystem.

The whole system scheme diagram is shown in figure 1.

According to the system's structure, the system can be divided into two main parts, they are mainframe and cooperation target. The mainframe is installed in the tracking spacecraft, the cooperation target is installed in the target spacecraft, the mainframe structure has two optional schemes, coaxial mode and multiple heads parallel mode. The optical system of the coaxial mode employs the same light path, then using prismatic means sends the light to

laser sensors and CCD sensor respectively. The mainframe structure of this scheme is compact, light, but the optical system is complicated, light loss is large, the reliability is somewhat affected.

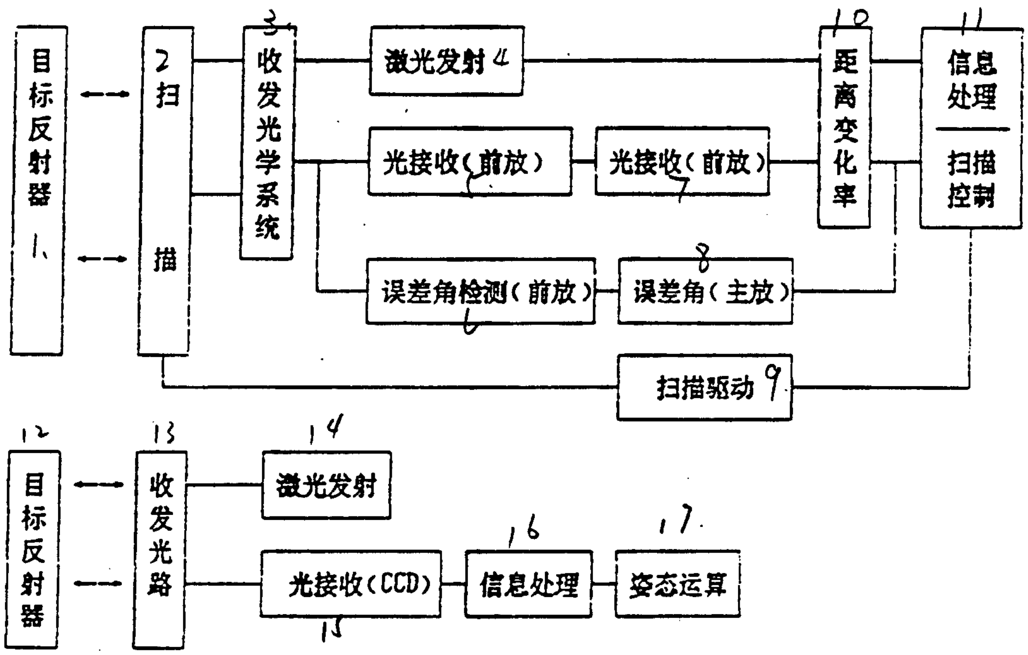

Figure 1. The whole system diagram

Key:

1. target reflector 2. scanning 3. receiving and sending optical system 4. laser emitting

5. laser receiving (pre-amplifier) 6. error angle detection (pre-amplifier)

7. laser receiving (pre-amplifier) 8. error angle (main amplifier) 9. scanning driving

10. distance varying rate 11. information processing, scanning control 12. target reflector

13. receiving and transmitting light path 14. laser emitting 15. laser receiving (CCD)

16. information processing 17. pointing computation

The multiple head parallel scheme is installing the sensors directly in their own telescopes. This not only overcomes the difficulty of multiple wave band large aperture light dissecting, but also free of image rotating problem. Because the two sensor systems are independent, it is convenient for installation, debugging and maintenance.

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5.2 Working principle

The laser radar processes capturing using the scanning mode. It utilizes the rough angle information (LOS angle) of the target spacecraft acquired by the microwave radar. Using this angle information as a standard, it makes the laser beam whose wave beam width is several mrad point to the target spacecraft, and uses galvanometer scanning reflecting mirror scan the area of 3° x 3°. The coordinated target which is installed in the target spacecraft reflects the laser signal back Through the receiving and sending coaxial optical system, the reflected laser signal is input respectively into the distance detector and the four quadrant angle tracking detector of the optical receiving device; after capturing the information of the target spacecraft, it drives and controls the galvanometer scanning mirror to make the error signal received by the four quadrant detector zero, then processes tracking and ranging. Within the area of 200 m and short range, CCD is used to detect the two dimensional image of the coordinated target installed in the target spacecraft, thus finishes the surveying of relative pointing.

RVD compound laser radar sensor is mainly used in the medium and short range searching, tracking, angle surveying, ranging. In addition to these functions, in the short range, it can also be used to process pointing angle surveying. The compound laser radar sensor's functions include three parts: searching and tracking, ranging, angle surveying (pointing

surveying). The following is the simple introduction to each part.

(1) Laser device

We selected the pulse and continuous wave semiconductor laser device as signal source, it has small size, low power, reliable, long life, and good compatibility with other electronic systems, it can satisfy the space application demands.

(2) Searching and tracking

In order to capture the signal from the angle reflector and to track the target, the tracking spacecraft employs the galvanometer coaxial scanning mechanism, the scanning large viewing field is $20° \times 20°$, the small viewing field is $3° \times 3°$.

(3) Ranging

In order to enhance the precision of ranging, we employ the continuous wave laser phase ranging method, in order to avoid the multiple values of the ranging, the ranging system employs the method of three kinds of audio frequency multiple stages modulation, thus ensure the precision demand of the system's ranging.

(4) Angle surveying

The target's angle surveying of the laser radar employs the four quadrant detecting method. The laser radar emits the laser signal to the target spacecraft, the signal is reflected by the target, through the optical system it inputs into the four quadrant detector. If the target reflecting optical signal has a deviation angle to the surveying optical axis, the facula projecting on the optical detector have different areas on the four quadrants. After being processed, we can get the relative angle error signal, then using this signal to drive the servo system, this makes the surveying system turn to the target, till the error angle becomes zero.

(5) Speed surveying

There are several methods of laser radar speed surveying,

the simplest one is to survey the increment varying of time; the more reliable and precise method is to survey the Doppler frequency shifting of the echo wave signal. There are two methods to survey the distance varying rate using Doppler frequency shifting. The first one is the audio frequency method, the other one is the laser frequency method. But currently, due to the wide spectral line of the semiconductor laser devices, there are some difficulties to use the laser frequency method, so the audio frequency method or the distance varying rate method is used to process the speed surveying in short range.

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(5) Pointing angle surveying --- CCD surveying sensor

Three CCD cameras with different focuses are installed in the laser radar. A wide angle laser beam is used to illuminate the reflector on the target spacecraft directly, then based on the imaging light point or image in the CCD cameras, after data processing, the relative distance and pointing can be acquired. In order to avoid variable solution, also a phase ranging device is needed to survey the distance. Using this method, the rotating pointing angle surveying precision we can get is 0.6° ~ 0.2°, pitch and deviation pointing angle surveying precision is 0.4° ~ 0.2°.

5.3 Working range estimation

1. Semiconductor pulse laser device

$$P_r = \frac{16 A_t A_r P_t K}{\pi^2 \theta_t \theta_r R^4}$$

where:

#2:

A_t: target effective area (ø 80 mm x 6)

A_t: receiver effective aperture area ø 80mm

A_r: laser emitting power 100W

K: total receiving and emitting optical system efficiency 0.5

Θ_t: laser emitting light beam angle 10 x 10^{-3} radian

Θ_r: angular reflecting light beam angle 0.1 x 10^{-3} radian

P_r: receiving device sensitivity: 1 x 10^{-6} W

From the above formula and parameters, we can get:

R = 33 Km

2. Semiconductor continuous wave laser device

A_t: target effective area (ø 80 * 6)

A_r: receiver effective aperture area ø 80mm, S = 5.024 x 10_{-3}

P_t: laser emitting power 100mW

K: total receiving and emitting optical system efficiency 0.5

Θ_t: laser emitting light beam angle 1 x 10^{-3} radian

Θ_r: angular reflecting light beam angle 0.1 x 10^{-3} radian

P_r: receiving device sensibility: 2 x 10^{-9} W (B = 20 Kc)

m: percentage modulation 0.8

From the above formula and parameters, we can get:

K = 26 Km

When P_t: laser emitting power is 0.2W, R = 31 Km

When P_t: laser emitting power is 0.3W, R = 35 Km

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6. The feasibility analysis

With the development of the laser device and laser technology in our country and foreign countries, the existing condition for researching and developing the laser radar surveying sensor for space docking is excellent. We will mainly analyze in the following several aspects:

(1) Reliability, small size, low power consumption

The space docking requires that the laser radar system is reliable, size is small, power consumption is low. Currently,

the average output power of the semiconductor laser device can reach 100 ~ 200mW, the maximum value can be several Watts. For a laser device power output of 100mW, its power consumption is only 2W, the power consumption for the whole system that is made up by these laser devices also consumed only several Watts. The diameter of a 100mW laser device usually is only several centimeters (4cm), average working lifetime can be several years. Besides, the laser device is capsulated inside the metal case, so the device is free from impact and vibration. We can see that, current laser semiconductor devices can satisfy the docking system's requirement for small size, reliability and low power consumption.

(2) Range, precision

Range: from the range formula of the laser radar we can see that, if we can enlarge the laser device's output power, reduce the laser device's wave beam angle, enhance the receiving device's sensitivity, control the coordinated target's machining precision, we can greatly enlarge the laser radar's working range.

As has been mentioned above, current laser device average power can be 0.1 ~ several Watt (the laser power used by Japan space docking is less than 1 Watt), this satisfies the basic requirement for the system.

Although the output wave beam angle of the semiconductor laser device is wide (dozens of radian), but the output window of the laser device can be very small (for 0.1W laser device, the emitting window can be 1 μm x 3 μm), so employing the self-focus lens can compress the wave beam angle to several milli-radian, or even smaller. In addition, the sensitivity of the current laser receiving detector can be 10^{-8} ~ 10^{-9} W. The incident angle of the coordinated target's optical angle reflector can be controlled around 2", that is 0.01 mrad.

The above parameters can prove that, for the docking system that is made up by current existing semiconductor laser

devices, it is feasible for its first stage obtains a range larger than 20Km.

Precision: The pulse laser ranging counts the pulse forward and return time to determine the distance. Its precision is limited by the pulse width, counter frequency and stability. Usually, current laser pulse width can be about 10ns, the counter utilizes the frequency of 150 MHz or even lower, the frequency stability is around 10^{-6}, the ranging precision is limited in the meter magnitude order. But for the continuous wave laser ranging, the phase ranging is employed, the ranging precision is relative to the modulation frequency, frequency stability. The ranging precision can be on the order of centimeters.

The laser radar uses a laser to detect the target, the light spot that is reflected into the four quadrant detector can be very small (0.1mm or even smaller), so the angle sensitivity that is reported in the four quadrant detector can be several or dozens of second angle.

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It is required that RVD auto rendezvous and docking laser radar has wide area range, large viewing field, high precision, these requirements bring many special problems that need to be solved. After several years research, in foreign countries, many key technologies have been advanced, they clear away the technical barriers for practical research. In order to adapt to the complicated environment in space, according to the present situation of our country and the need for the auto rendezvous and docking laser radar, we must develop the following key technologies.

1. Semiconductor laser device wave beam compression and compound technology

The semiconductor diode laser device is different from most of the laser devices, it emits light beams inside a relative large spatial angle (40° ~ 50°), so it needs an

optical system to compress the radiation and make it be a narrow beam. In order to collect the laser energy as much as possible, it is required to utilize a special optical system, design a very low consumption rate optical system which uses the effective method of compressing wave beam.

In order to survey distance and relative pointing, the distance detector and position detector are needed, the frequency responses of these two detectors are very different. When the distance precision is required to be higher, the higher modulation frequency is needed, then the position detector can not respond to this high frequency. Now the laser device that has two different modulation frequencies is employed. After polar synthesis and polar dialysis, it can satisfy the requirement of both ranging and angle surveying.

2. Wide area, high precision phase ranging technology

Because RVD laser radar is used for the surveying range from 50 Km to 0 m, the emitting system needs several different modulation frequencies to ensure the precision of the ranging. The receiving system needs a amplifier with large dynamic range thus to ensure that system not only does not saturate, but also has high sensitivity. In order to ensure that it can survey the distance of 0 m, the system employs the optical fiber delay method. If the phase ranging technology is employed at the same time, the surveying precision can be greatly enhanced.

3. Receiving and emitting scanning synchronization control technology

It is required that the emitting light axis and the receiving light axis are parallel and collimate, scanning employs the galvanometer dual-axis deflexion mechanism. The detector makes the large area devices synchronized with the scanning device, compounds the laser device active scanning with the large area, thus not only satisfies the relative large viewing field, but also meets the high precision demand, at the same time, the shared receiving and emitting optical

system is employed.

4. Image signal processing technology research

The coordinated target reflecting laser imaging is processed through pre-processor, identifier, classifier, and a 33MHz 486 PC with an 860 processing card that can process the image in real time, thus the target classifying and identifying is processed in real time. The emphasis should be put on research and application of SAW-FFT, and other relative signal processing technology, thus processing all kinds of information, meet the high speed large capacity processing demand of precise ranging, speed surveying, angle surveying, and imaging identifying and selecting.

5. The emulation and semi-physical simulation technology of RVD surveying system

It is very difficult to process the RVD surveying system's orbital flying experiment. Cutting the times of RVD orbital flying experiments as much as possible is decisive for saving more research funds and shortening the research cycle. It is needed to process RVD surveying system's digital emulation and semi-physics emulation according to the different developing and researching stages.

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Missile's guidance head anti nuclear electromagnetic pulse reinforcement

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Abstract: In the nuclear weapon family, following A-bombs and H-bombs, some countries developed and produced some other kinds of nuclear weapons, the nuclear electromagnetic pulse bomb is one of them. This kind of nuclear bomb is mainly used to interfere or damage un-reinforced electric and electronic systems. Un-reinforced missile guidance heads also could be damaged.

So, this paper simply introduces the generation and main characteristics of the nuclear electromagnetic pulse, the damaging mechanism of the nuclear electromagnetic pulse to the guidance head, and the response of electronic devices to the nuclear electromagnetic pulse, at last introduces the guidance head's defense method to the nuclear electromagnetic pulse.

Keyword: nuclear electromagnetic pulse, nuclear electromagnetic pulse damaging mechanism, anti nuclear electromagnetic pulse reinforce

The electromagnetic pulse produced by a nuclear weapon explosion is called nuclear electromagnetic pulse (NEMP). It is mainly formed by the irradiation after nuclear explosions and the Compton collision among media around the nuclear explosion, it is a kind of transient electromagnetic field.

The excitation of NEMP to the missile is similar to the excitation of the electromagnetic wave to antennas. It induces very high voltage and very strong current in the missile, this voltage and current are transmitted into the missile's interior, cause temporary or permanent damaging effects to the electronic devices in the guidance head. Therefore, it is necessary to reinforce the guidance head to anti NEMP.

1. The nuclear electromagnetic pulse effect

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1.1 NEMP

The explosion of nuclear weapons can be approximately divided into high altitude explosion, low altitude explosion and ground explosion. The explosion height of high altitude nuclear explosions is from dozens of

kilometers to several hundreds kilometers. The ground explosion is the nuclear explosion on the earth surface or near the earth surface. These explosions all produce NEMP. To a great extent, the characteristic of NEMP is determined by the nuclear weapon equivalent mass and nuclear explosion height.

If the gamma ray produced by the nuclear explosion directly acts on the guidance head, it will excite electrons inside the guidance head, thus producing electromagnetic field in the guidance head, this is called internal electromagnetic pulse (IEMP). When the high altitude nuclear explosion happens, due to the very long distance of nuclear irradiation, it will cover very large areas, when the air defense missile and ballistic missile and other aircraft fly through the area of strong gamma ray dosage, the guidance heads interior will create IEMP, it will interfere with or damage the guidance head.

1.2 The main characteristics of NEMP

1.2.1 Field intensity

The field intensity of the electromagnetic pulse (EMP) produced by air explosion radiation is determined by the equivalent mass, explosion height (because of the density gradient of the atmosphere, the effect of height is asymmetrical) of the nuclear explosion and the asymmetry [1] due to the weapons (including auxiliary equipment, shell case or launching vehicle). For the low frequency EMP produced by the difference of air density, at a random specified time t, the radiation electronic field E(t) that is observed is :

$$E(t) = \frac{r_0}{r} E_0(t) \sin\theta \qquad (v/m)$$

where, r is the distance to the explosion center outside the source area

r0 is the radius of the source area

If we compute E0(t) under specific conditions using r0 = 0. 32lnQ + 0. 48 (Km), E0(t) is usually from dozens of Volts per meter to several hundreds volts per meter.

In the ground explosion, the radiation electronic field peak values at the source area's boundary along the earth's surface direction is 10 ~ 100 times bigger than that of the air explosion of the same equivalent. The peak value irradiation electronic field along the earth's surface direction changes with the distance r:

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$$E = \frac{r_0}{r} E_0$$

where, E0 is the peak value radiation field intensity at the source area's radius r0, it is usually several thousand volts per meter.

The relationship between the range and explosion height of NEMP is showed in table 1 and figure 1. Figure 1 shows the electronic field peak value changing at different places on the earth's surface where the explosion height is 100 ~ 500 Km, equivalent mass is 100 Kt, explosion center's projected point is in the area of north latitude 30°~60°

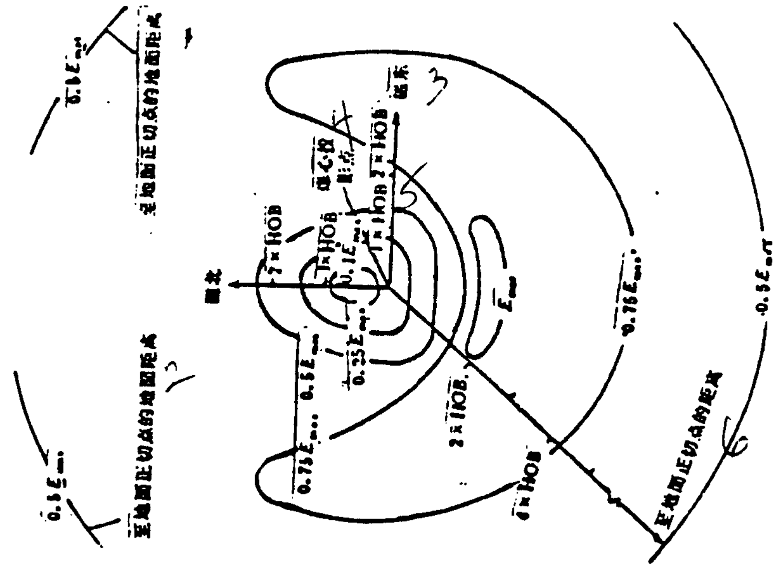

Figure 1. The electronic field peak value changing at different places on the earth's surface in high altitude nuclear explosions.

Key:

1. The ground distance to the ground surface's tangent point
2. The ground distance to the ground surface's tangent point
3. magnetic field north 4. explosion center's projected point
5. magnetic field east 6. The distance to the ground surface's tangent point

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The low frequency field (10 ~ 20 KHz) of NEMP is very strong, approximately 1Hz～300MHz; but because the high frequency field is absorbed and there is a rapid decrease in the transmission period, in the not far distance, the field intensity is possibly very small.

Table 1. The range of the nuclear electromagnetic pulse of different heights

1 爆炸高度(km)	100	150	200	300	400	500
2 从爆心"看"到地球的半径(km)	1120	1370	1580	1923	2250	2450

Key: 1. explosion height (Km) 2. the earth's radius viewed from the explosion center

The NEMP's spectrum is from 1Hz to more than 300 MHz [3], shown in figure 2. Usually, NEMP's main frequency produced by H-bomb explosions is around 7 ~ 8. 0 MHz; in the A-bomb explosion, about 95% of the main frequency is around 15. 25 ~ 18. 99 MHz, the spectra are different according to the explosion center distance [4]. The distance increases, the field intensity's high frequency energy loss is larger than that of the low frequency energy, so in the far area, the spectrum distributes below 100 KHz.

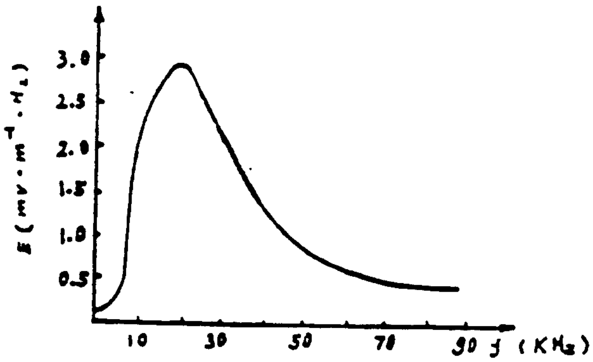

Figure 2. The spectrum distribution of the nuclear electromagnetic pulse

The spectrum can usually be divided into three areas: 1) source area: if the pulse width is 0. 1 ~ 0. 2 μs, the energy mainly concentrates in the range below 5 ~ 10 KHz; if the leading edge is 0. 01 μs, the upper limit of the spectrum is about 100 KHz; 2) transition area: the energy mainly concentrates in the range from several hundred Hz to 150 KHz,

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3) radiation area: the energy mainly concentrates in the range from several hundred Hz to 50 KHz, the peak value appears around 10 ~ 20 KHz [5].

In brief, the leading edge of NEMP is steep, in the 10^{-8} second period of gamma ray radiation, it rises from 0 to the maximum of about $5X10^5$v/m, the pulse width is about 10 ~ 30 μs, the field intensity can reach 100 ampere * turn / meter. Figure 3 shows the comparison of NEMP and lightning and radar pulse.

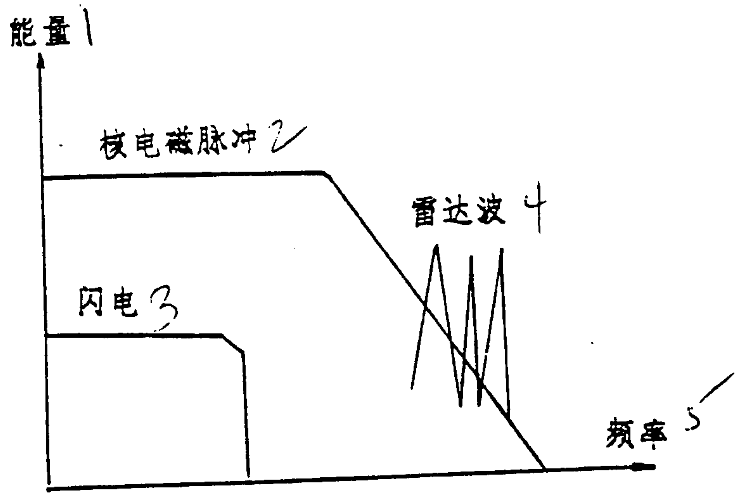

Figure 3. The comparison of NEMP and lightning and radar pulse
Key: 1. energy 2. nuclear electromagnetic pulse 3. lightning
4. radar wave 5. frequency

1. 3 The mechanism of how NEMP damages the missile's guidance head

The coupling of the guidance head to the NEMP can be divided in three ways: electronic induced coupling, magnetic induced coupling and resistance coupling. The electronic induced coupling produces induced current on the conductor's surface. The magnetic induced coupling appears in the conductors that form the closed loop, in this loop, it causes current flow. The form of the loop can be invisible or radome connected conductors. The resistance coupling appears when the conductor immerses in the conducting media, such as the air of electronic ions, it produces induced current. From these factors, we can say that all conductors can get energy from NEMP field by coupling. In this circumstance, the missile's cover, guidance head's shell become the NEMP energy collectors.

Because the spectrum of NEMP is very wide, there always exists a part of the energy that can be effectively

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absorbed by coupling. Usually, the larger the missile's area, the longer the missile, the more energy would be collected. The energy collected by the missile is converted into strong current and very high voltage, thus the electronic devices inside the guidance head could be badly damaged and cannot work normally.

1. 4 The nuclear electromagnetic pulse response of electronic devices

NEMP has a temporary effect or permanent effect on the electronic devices. The permanent effect causes permanent damage, the devices cannot work without repair.

What kind of effect can be produced depends on the energy threshold

of the damage, it usually relates to the following aspects: how much energy the electronic devices collect, the quantity that the sensitive and easily damaged devices get, and the sensitivity of the devices or the circuits themselves.

The devices that easily generate permanent effects are: the semiconductor node of semiconductor devices (especially high frequency transistor, integrated circuit and microwave diode), integrated circuits, especially large scale integrated circuit, insulated radio frequency cable, power supply cable, rated power or very low voltage electronic devices, and precise devices, etc. The minimum energies in Joule which cause permanent damage to some devices are shown in table 2.

Table 2. The minimum energies in Joule cause permanent damage to some devices

名称 1	最低焦耳能量* 2	故障 3	说明 4
2N36	4×10^{-2}	烧毁 5	锗声频晶体管
2N3528	3×10^{-3}	烧毁 6	硅可控整流器 8
7 继电器	1×10^{-1}	9 接点熔焊	西格马(IIF)1A 继电器 10
11 集成电路	4×10^{-10}	电路失灵 12	西凡尼亚 J-K 触发单块集成电路(SF50) 14
13 磁芯	2×10^{-9}	接线抹擦	布罗快速计算机磁芯存贮器 (FC2001) 17
18 放大器	4×10^{-11}	干扰	19

Key: 1. Name 2. minimum energy in Joule 3. damage 4. description 5. burn down 6. germanium voice frequency transistor 7. burn down 8. silicon controlled rectifier 9. relay 10. connection point desoldered 11. Sigma (IIF) 1A relay 12. integrated circuit 13. circuit malfunction 14. Sylvania J-K flip-flop single integrated circuit (SF50) 15. magnetic core 16. wire smearing 17. Burroughs high speed computer magnetic core memory (FC2001) 18. amplifier 19. interference

* NEMP's damaging effect on electronic devices can be indicated by "minimum energy in Joule"

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The devices or components that easily generate transient effects include: low power or high speed digital processing system, the wired connected memory, and flight control system, etc.

2. Anti electromagnetic pulse reinforcement

From above descriptions we know that the missile's guidance head must have anti NEMP reinforcement. There are many methods of reinforcement, before reinforcement, the effect of each reinforcement should be considered.

The degree of the reinforcement should depend on the total tactical and technical index of anti NEMP. According to this index, each subsystem of the guidance head should be considered, then determine which devices in the subsystem should be reinforced and the reinforcement index that they should have, and which devices need not be reinforced.

The total index depends on the NEMP environment that the guidance

head is in. Some people think, $5x10^4 v/m$ is the standard NEMP environment.

In addition, the reinforced guidance head should: 1) be able to endure the testing; 2) during the effective life time of the guidance head, this kind of reinforcement can be kept and maintained.

2.1 shielding

Shielding is an effective method to reduce the NEMP environment level. Shielding can be divided into static shielding, magnetostatic shielding and electromagnetic shielding.

2.1.1 Static shielding

The static shielding is mainly to isolate the electric power wire. One of the important ways is to connect the shielding unit to the earth, maintain the earth's electric potential of the shielding unit.

2.1.2 Magnetostatic shielding

The magnetostatic shielding can compress the magnetic field lines in the range of the shielding unit's thickness, thus producing the effect of magnetostatic shielding. The crack or aperture of magnetostatic shielding should not cut off the magnetic field lines, otherwise the shielding effect would be reduced. If the shielding unit is connected to the earth, this method also has the effect of static shielding. The magnetic field intensity of NEMP can reach 100 ampere * turn / meter. If the frequency is lower than 100 KHz, the magnetic shielding is relatively

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difficult. The shielding performance can only be realized by experiment.

2.1.3 Electromagnetic shielding

The principle of electromagnetic shielding depends on the energy reflecting loss of the high frequency electromagnetic wave on the shielding unit's surface and the high frequency energy's whirlpool loss within the shielding unit's thickness. In fact, the electromagnetic shielding is the summation of reflecting loss, absorbing loss, and the correction term causing multiple reflecting (when the absorbing loss is small, this term cannot be ignored).

In addition, the circuit layout inside the guidance head should avoid loop circuit layout (figure 4a), and should employ the tree layout as shown in figure 4b, thus avoiding latent "loop antenna", causing magnetic coupling and absorbing NEMP energy.

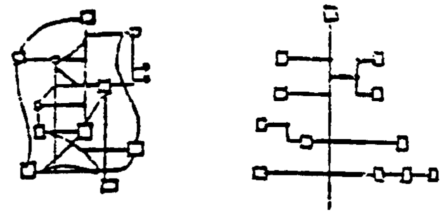

Figure 4

(a) loop layout (b) tree layout

2. 1. 4 The effect of the shielding unit's discontinuity.

The joint-free shielding unit without cracks or continuous slots is a kind of ideal structure. But the I/O port of the power supply cable and control cable, and sensor opening, etc. are required. These cause discontinuous areas, affect the shielding performance of the guidance head shell, so, the design and manufacture of the discontinuous area are very important.

2.2 Employing amplitude limiting technique and filtering technique [6]

In addition to the above mentioned methods, the amplitude limiting technique and filtering technique could be employed in the guidance head to stop or absorb useless and error signals, only allowing the useful signals to pass. 1) voltage amplitude limiter

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(undulation restraint), in the key circuit this device can be used to limit the voltage, the devices that can limit the amplitude include: medium breakdown devices (such as spark gap), semiconductor breakdown devices (such as Zener voltage stabilizing diode) and nonlinear breakdown resistance (voltage dependent resistance). The amplitude limiting level should be higher than the working level.

Because the leading edge of NEMP rises rapidly and its energy is large, considering the working characteristic of the amplitude limiting devices, the amplitude limiting devices should be used associated with the filtering devices to accomplish the task. 2) Filter: the filters used for NEMP reinforcement usually include two kinds, they are T shape and Π shape, but the Π shape low pass filter should be avoided, because high voltage can possibly affect the input capacity of this filter and cause the capacity's performance to be damaged or out of order. Because it is difficult to manufacture the heavy current filter whose cut off frequency is below 10 KHz, it is better to use the filters in pairs adjacent to the amplitude limiting devices. Besides, the following should be paid attention to: the input and output of the filter should have radio frequency insulation or shielding, install one filter or one of the multiple filter in each power supply wire, and must confirm the good ground connection to the shell and the filter box.

2.3 Improve circuit design, select reinforced parts to use

Improve circuit design and use protection circuits to avoid NEMP interference, for example, using digital logic circuits with high voltage and switch matrix instead of those switching circuits which depend on the signal fluctuation rate. Using shielding cable or optical cable instead of ordinary cable, the integrated circuit produced using sapphire (SOS) technology, the computer memory system uses magnetic drums or disks that are not easily reversed.

2.4 Ground connection

Good ground connection is useful to reduce the system's vulnerability to the NEMP, the "ground" always is viewed as a part of the circuit, it has relatively low resistance for local ground where it connected. From the viewpoint of anti NEMP, the better method is to provide a series of circuits with a single ground connection point that has the lowest resistance.

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2.5 Protection against the Internal Electromagnetic Pulse (IEMP)

The electromagnetic shielding is only effective for the EMP transmitting in the atmosphere and has no effect for IEMP, because IEMP is generated inside the guidance head.

The protection devices against IEMP include: 1) employing the low atomic number materials (such as plastic foam and other hydrocarbons) as isolating layer or filling. 2) the arrangment of devices and units should be reasonable, the wire should as short as possible; if long wire is required, then twisted wire should be employed, 3) select ground connection point, for one unit, there should not be multiple ground connection points. 4) employ multiple layer shielding; use anti-radiation cable, 5) reduce the free space volume inside the guidance head.

Conclusion

Anti NEMP reinforcement is systematic engineering, each link should be considered according to the design requirement. The carelessness of one link may cause critical results, even cause the malfunction of the whole protection system.

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Land Based Guided Missile

Anti Thermal Infrared Camouflage Net Research

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Abstract: Since the 1980's, many researchers considered thermal infrared camouflage as the main field of camouflage research subject. Anti infrared camouflage nets have been widely utilized in the mobile target. The basic technologies of the anti infrared camouflage net for the land based guided missile will be discussed here.

Keyword: Land based guided missile, Thermal infrared camouflage Camouflage net

1. Foreword

Military and strategic experts in every country recognized that the vital importance of military camouflage is to provide protection. Around the world, there were many examples of using camouflage and deceiving tricks for which proved the importance of camouflage during a war. In several high tech. regional wars in recent years, we can see that the continuous development of new weapon systems and the increasing war power of coordinated multiple forces, especially with highly developed modern reconnaissance technologies and means. All these have made the camouflage increasingly important in warfare.

Land based guided missile force have combined high technology and double strike forces (nuclear strike force and conventional strike force). So this became more important than ever in modern war. The guided missile force has the character of being easy to detect in a war, because it has more large equipment, and it is a large moving target. Camouflaging is the best means to increase land based guided missile reaction ability and

battle field survivability. Hence it can carried out the "hide and strike" strategy.

In modern reconnaissance and offense, infrared technologies have been widely adapted. For reconnaissance, thermal infrared detection technology was already the main source of information for battle field targets. For offensive action, the main strike forces in the battlefield are all kinds of infrared guidance weapons. Since the 1980's, thermal infrared camouflage is the major research subject in the camouflage field. There are many results from this research. Currently the most widely adapted method is the anti infrared camouflage net, and thermal infrared paint (coating) and infrared smoke. Infrared smoke has many limitations during deployment, which restrict the range of application; currently its been used mainly for short term camouflage. As for infrared paint or coatings, there are technical problems concerning the process of spreading and drying which needs to be solved, and its applications are also restricted. Anti infrared camouflage net can be extensively used with mobile targets, therefore, it is superior than other technologies.

A dedicated camouflage net for the land based guided missile is a modern camouflage system, which can be used in different environments against all kinds of different infrared sensors. Besides excellent anti thermal infrared character, it can also be used against the detection of visible light, near infrared, and radar sersors. This dedicated camouflage net can effectively protect the "hot target" like land based guided missile (and equipment on the ground),

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It can also provide protection for tanks, or artillery after certain improvements are made to enhance those weapons' battle field survivability.

2. The scheme for land based guided missile dedicated camouflage net

technology

We distinguish modern reconnaissance by the electromegnetic wave spectrum into three catagories - there are visible light reconnaissance (including near infrared reconnaissance), radar reconnaissance, and thermal infrared reconnaissance. There are also three different kinds of camouflage equipment. Optical and near infrared camouflage equipment has been matured for a long time, in the 70's the US army and Swedes successfully developed and equipped armed forces with radar camouflage nets and other related camouflage equipment. It's been a long time that researchers have been looking into thermal infrared image sensing camouflage equipment. Because there are special features in thermal infrared technology especially suited for military reconnaissance, and, because of the mass application of the thermal guidance homing weapons, conventional camouflage equipment is useless for protection against these new weapon. Therefore, thermal sensing technology has been recognized as the ultimate threat to the millitary target. And hence thermal camouflage technology has been recognized as a difficult problem. In the 70's the US started research on thermal camouflage technology. But it "has not been able to find an effective protection against the thermal quidance sensing devices, even now, all efforts for protection of precious targets against thermal monitoring and thermal guidanced missile attack are to no avail." At the late 80's up to the beginning of the 90's, gradually some new progress have been developed using thermal camouflage technology.

The basic technological scheme for land based quided missles dedicated anti infrared camouflage nets:

1. Use the thermal shielding method to reduce the thermal radiation. First cover the quided missile with a thermal insulation blanket, to insulate the thermal radiation from the target. The thermal insulation blanket has been coated with low radiation material. With the shielding effect of the thermal insulation blanket, the thermal exposure of the target can be largely reduced. There are some small puncture holes in the

thermal insulation blankets for venting the hot air from the target. This reduces the surface temperature of the thermal insulation blanket.

2. Cover the thermal insulation blanket with another thermal camouflage net, which has different surface thermal radiation character in different parts of the net. This camouflage net with the thermal insulation blanket together can change the thermal character of the target to be close to the surrounding environment. On the back of the thermal camouflage net, there is a layer of reflective material, this reflective layer on the one hand can diffuse the heat radiation from the thermal insulation blanket, and prevent the thermal camouflage net from heated up, this part of the reflected heat can be carried away by the convective air flow between the thermal camouflage net and the thermal insulation blanket. This greatly reduces the heat radiation penetrating through the thermal camouflage net. In this way, the thermal radiation from the thermal camouflage net will match the atmospheric and surrounding terrian background "cold" radiation. Secondly, this reflective layer is also the primary reflective layer for the radar diffusive net. Therefore, this thermal camouflage net can be used as anti radar device.

3. Conclusion

From above discussion, research on land based guided missile dedicated anti infrared camouflage nets, will aggresively push the development of guided missile camouflage technology. In these days of the fast development of reconnaissance technology, we shall keep integrating the new technology to apply to the guided missile camouflage to enhance its survivalbility in future wars.